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GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA.

N. H. WINCHELL, State Geologist.

BULLETIN NO. 6.

THE

IRON ORES OF MINNESOTA,

THEIR

GEOLOGY, DISCOVERY, DEVELOPMENT, QUALITIES, AND
ORIGIN, AND COMPARISON WITH THOSE OF
OTHER IRON DISTRICTS,

WITH A

GEOLOGICAL MAP, 26 FIGURES AND 44 PLATES.

BY N. H. WINCHELL AND H. V. WINCHELL.

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THE IRON ORES OF MINNESOTA.

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CORRIGENDA.

Page 39, seventh line, for "eruptions" read eruptives.

Page 39, tenth line, for "this" read thin.

Page 71, fifth line from the bottom, for "microscopic" read macroscopic.

Page 76, tenth line from the bottom, for "deposition" read disposition.

Page 77, second line from the bottom, for "microscopic" read macroscopic.

Page 78, seventeenth line, for "scabs" read scales.

Page 106, fifth line from the bottom, for "distributed" read disturbed.

Page 209, thirty-first line, insert .45 in the blank space at the right.

PREFACE.

This bulletin is the direct outgrowth of a law passed by the Minnesota Legislature in 1887 requiring the state geologist to make special examinations for the discovery of any economic product, which he might have reason to believe existed at any place in the rocks of the state, and to report thereon for the information of the citizens of the state. Ten thousand dollars were appropriated for these special researches and tests. There was first an effort made to find natural gas, and the report thereon is published in bulletin No. 5. Attention was then directed to the northern part of the state with a view to make such drilling-tests as would throw light on the extension of the Mesabi range through the region between Mesabi station and Pokegama falls on the Mississippi river. It became at once apparent that the entire sum of money appropriated would not pay the cost of any such special, thorough, and practical testing for iron ore as the law contemplated, and that therefore it would be necessary, in order that the law and the appropriation be not defeated in their purpose wholly, to make a more general survey and report on the iron ores of the state. This examination was expanded rapidly into a very important and far-reaching investigation, and the report herewith, while employing all the data that had already been gathered by the survey directed solely to this object, is based very largely on new facts and surveys made available through this special law. Therefore, while embodying one of the results contemplated by the general law of the survey, it appears now as a diversion from the regular course of the work of the survey, and should not be considered as its final statement on the iron ores of the state.

We have attempted to give, in this bulletin, such information concerning the iron ores of Minnesota as might be wanted by the explorer, the miner, the geologist and the citizen of the state. There has been a great demand recently for such a discussion of the iron ores of the Northwest. As the discovery of new mining grounds has, year after year, extended the interest in iron mining among a greater number of individuals and corporations who naturally look to the official survey for information and guidance, so have the number and complexity of the problems involved increased. We have not essayed the settlement of all the scientific

questions that have arisen through this extension of the field of observation. We have simply collected the new facts as we have learned them and have made an initial effort to group all of them, both old and new, under a classification intended to make them indicate some general principles. Our results are not wholly in accord with those of some of our predecessors—as theirs were not with theirs. We would have been glad to have taken more time for further field and laboratory work. It is evident, however, that we should never reach perfection. It was equally evident that justice to a large and expectant constituency required the preparation of a report on the iron ores, however far it might fall short of rendering justice to the subject. It is only through successive partial studies, and the publication of the incompleated results that some additions are made to our knowledge of the geology of the ores of iron. Our contribution to that fund of knowledge will go with others, both earlier and later, to enable some fortunate future geologist to prepare an exposition that will be both thorough and complete. We shall be satisfied if we may be able to add a small quantum to that end.

We may, however, mention those parts of this report which we consider as presenting features that embody original views, or new combinations of well known facts, or that will be found to be of particular value to the geologist or the practical mining man.

1. The separation of the ores of the Northwest into two geological formations, and those of Minnesota into four formations, and the special description of each. This has never before been done except by us in some of our preliminary papers.

2. The differentiation, and yet the genetic derivation, of the crystalline schists and their ores from the greenish, fissile schists of the Keewatin and their ores.

3. The demonstration of the chemical precipitation, in Keewatin time, of the chalcedonic silica of the jaspilyte, in the bottom of the Keewatin ocean.

4. The deep-sea origin, as a chemical precipitate, of the associated hematite of the mines of the Vermilion range, and to a large extent of those of the Mesabi range.

5. The primordial, *i. e.*, Taconic, age of the ores of the Mesabi range.

6. The primordial, *i. e.*, Taconic, age of the gabbro of the Mesabi range, and hence of the associated granites and the contained titanite magnetites.

7. The theory which is maintained for the origin of the iron ores of Keewatin age contains some new elements, and is essentially

a new theory. But we advance it confidently, believing that the evidence abundantly justifies the conclusions.

8. The bibliography of the origin of iron ores is something which we have not seen elsewhere, and which we believe future students will find particularly useful.

9. The lists of mining corporations and land leases for mining, and the glossary of mining and geological terms, will be found useful and convenient by all mine operators and interested capitalists—more especially those of Minnesota.

10. Although the general trend only of the geological formations is shown on the accompanying map in the western part of the area included in it, still as a whole the map is an advance on all previous maps, and in the eastern part it is largely based on positive facts of observation.

We cheerfully acknowledge assistance that we have received in the preparation of this report. Everywhere we have been received by mining communities and by representatives of railroad and mining corporations with the utmost cordiality, and have been afforded every facility to make such examinations as we desired. We wish specially to thank the Minnesota Iron Company, the Chandler Iron Company, and the Duluth and Iron Range Railroad Company. Personal favors, and special information have been afforded by Mr. George C. Stone, St. Paul, Superintendent D. H. Bacon, Tower, T. B. Hoover, Duluth, G. C. Greenwood, Duluth, John Mallmann, Mesaba, H. A. Wilcox, C. T. Waters and Capt. R. J. Williams, Tower, Superintendent Jos. Sellwood, Capt. John Pengilly, Capt. Henry Roberts, Capt. Philip Scadden and Superintendent McQuade, of Ely, Mr. Eli Griffin, Minneapolis, and Henry Mayhew, of Grand Marais. We have also to acknowledge favors from the American Diamond Rock-boring Company, Chicago, E. P. Allis and Company, Milwaukee, the Ingersoll-Sergeant Rock-drill Company and the Rand Drill Company, of New York.

N. H. WINCHELL AND H. V. WINCHELL.

Minneapolis, March 10, 1891.

THE IRON ORES OF MINNESOTA.

PART I.

THEIR GEOLOGY AND DISTRIBUTION.

INTRODUCTION AND GENERAL CONSIDERATIONS.

Recentness of the development of the Minnesota ores. The development of the iron ores of Minnesota is of recent date. It is so recent, and has been so rapid and so great that the importance of the industry has not yet come to be realized except by a few who are closely associated with it, or who are themselves interested in other iron districts and have consequently felt the impress it has produced on the iron industry, in general, of the whole country. Although iron ore was known to exist in considerable quantities in the northern part of the state since the official announcement of the same by the state geologist in 1865,* no practical mining of it was attempted till 1884. The shipments of ore from Two Harbors on the north shore of lake Superior, for the six seasons during which the mines have been worked is as follows:

Shipments for 1884†.....	62,124 tons
Shipments for 1885.....	225,484 tons
Shipments for 1886.....	307,948 tons
Shipments for 1887.....	394 910 tons
Shipments for 1888.....	511,953 tons
Shipments for 1889.....	844,638 tons
Total product of the six years.....	2,347,057 tons

This product, prior to 1888, was the output of a single company, from the *Minnesota mine*, at Tower; but in the years 1888 and 1889, the *Chandler mine*, at Ely, produced 56,712 tons and over 306,000 tons respectively, and in 1889, the *Pioneer mine*, also at Ely, shipped 3,100 tons. Of all iron districts in the country the lake Superior district is the most productive, and has shown the largest results from short exploitation; yet in the lake Superior region in its whole history no mine has produced in the third year of its operation as large a tonnage as the Chandler produced in its

*H. H. Eames, Report on the metalliferous region bordering on lake Superior, 1866, p. 11.

†Shipments of iron ore are in long tons of 2240 pounds.

second year, and there are no two mines in the entire lake Superior region whose combined product for any one year equals that of the Minnesota and Chandler mines. For these six years there has been a consecutive increase over the previous year's product as follows:

Increase of 1885 over 1884.....	259 per cent.
Increase of 1886 over 1885.....	36 per cent.
Increase of 1887 over 1886.....	28 per cent.
Increase of 1888 over 1887.....	30 per cent.
Increase of 1889 over 1888.....	65 per cent.

The increase in the Marquette district during the same six years was as follows:

Increase of 1885 less than 1884.....	8 per cent. (decrease)
Increase of 1886 over 1885.....	14 per cent.
Increase of 1887 over 1886.....	14½ per cent.
Increase of 1888 over 1887.....	3½ per cent.
Increase of 1889 over 1888.....	26 per cent.

The increase in the Menominee district (Wisconsin and Michigan) for the same years was as follows:

Increase of 1885 less than 1884.....	20 per cent. (decrease)
Increase of 1886 over 1885.....	26 per cent.
Increase of 1887 over 1886.....	34 per cent.
Increase of 1888 less than 1887.....	3 per cent. (decrease)
Increase of 1889 over 1888.....	43 per cent.

For the Gogebic range (Wisconsin and Michigan) the corresponding ratios are expressed as below:

Increase of 1885 over 1884.....	11,601 per cent.
Increase of 1886 over 1885.....	541 per cent.
Increase of 1887 over 1886.....	70 per cent.
Increase of 1888 over 1887.....	11 per cent.
Increase of 1889 over 1888.....	23½ per cent.

It appears, therefore, that during the four years prior to 1890 there was a loss in the average rate of increase in all the lake Superior districts, except the Vermilion district, and that in 1889 the rate of increase in the Vermilion district was more than double that of the same year for the Marquette and the Gogebic ranges and was more than one-third faster than that of the Menominee district.*

The development of such an iron product in so short a time is an event of more than local significance, and demands the attention of all who are interested in the iron industries of the country.

Changes and improvements. The iron ores of the Northwest, especially known as those of the lake Superior district, were discovered by surveyors employed under the state geologist of Michigan,

*Owing to delay in the printing of this report it is now possible (December 8, 1890), to add the aggregate shipment of the Minnesota mines in the season of 1890. It amounted to 880,290 tons.

Douglass Houghton, in 1844. In 1846, a short account of the iron deposits near Negaunee was published by Jacob Houghton, Jr., and F. W. Bristol.* In 1851, two United States geologists, Messrs. Foster and Whitney, made the first systematic examination and report on the geology of the iron ores of Michigan.† In 1873 was published the report of T. B. Brooks, as one of the state geologists of Michigan, on the iron-bearing rocks of that state, and a few years later that of Dr. C. Rominger, of the same survey, on the rocks of the same region.‡ These valuable and reliable reports, it is needless to state, have served as authority on all the questions therein discussed, and have aided, in many ways, in the material no less than in the scientific development of the iron ores of the Northwest. At still later date, though before the practical exploitation of the iron ores of the Gogebic district, the geology of the rocks of the Penokee-Gogebic range has been presented systematically by the Wisconsin geological survey concluded by Prof. T. C. Chamberlin.||

As time has passed, since the publication of the report of major Brooks on the ores of Michigan, changes have taken place both in the mining methods and in the market demands, and discoveries have been made in the geological environments of the ore bodies. New competitive iron districts have been opened up and new cen-

* Mineral region of lake Superior, by Jacob Houghton, Jr., and F. W. Bristol, 109 pp. and map, 1846, Detroit, contains reports by Burt, Hubbard, D. Houghton and Stannard.

† Report on the geology of the lake Superior land district, Part II, The iron region, by J. W. Foster and J. D. Whitney, 1851. Much of the information given in this report was gathered under the direction of Dr. C. T. Jackson, who had charge of the survey from 1847 to 1849. His plans and his work seem to have been interrupted and discarded without sufficient known cause, and the credit of the final report was transferred to other hands which perhaps were not wholly friendly to Dr. Jackson. Some evidence of this is found in that *rara avis* of American geological publications, *Sen. Doc. 1st Sess. 31st Cong. 1849-50, III, pp. 371-935*. Jackson directly refers to it in A. A. A. S., 1849, Cambridge meeting, p. 283. The transfer to Foster and Whitney was owing to a change in the political control of the U. S. government. There is also another edition of Dr. Jackson's reports and accompanying documents, having paging from 355 to 919, but this embraces, beginning at p. 786, "Reports on the linear surveys, with reference to mines and minerals in the northern peninsula of Michigan in the year 1845 and 1846," being the report of Wm. A. Surt and Bela Hubbard on the work under charge of Dr. Douglass Houghton, state geologist of Michigan for 1845, and Burt's geological report on the same, continued after Dr. Houghton's death, for 1846. See also "Memoir of Dr. Douglass Houghton," by Alvah Bradish, Detroit, 1889, p. 295.

‡ Geological survey of Michigan, 1869-73, accompanied by an atlas of maps, Vol. 1, Part I. Iron-bearing rocks, T. B. Brooks, 1873. Also Vol. 2, appendices to Vol. 1, Part 1, T. B. Brooks.

§ Geological survey of Michigan, Upper peninsula, 1878-1880, accompanied by a geological map, Vol. IV, C. Rominger, 1881.

|| Geology of Wisconsin, in four volumes, 1873 to 1879, with large geological atlas, in sheets. The crystalline rocks are presented in various parts of all these volumes, the contributors being Profs. T. C. Chamberlin and R. D. Irving, E. T. Sweet, C. E. Wright, A. A. Julien, Arthur Wichmann, T. B. Brooks, R. Pumpelly, F. H. King and C. R. Van Hise.

tres of iron-making, necessitating new routes of transportation, have been established. These facts alone would warrant a new discussion of the iron ores of the Northwest, but when in addition, one of the most remarkable iron districts has sprung up within the limits of Minnesota, where, less than ten years ago, the country was in its primeval condition undisturbed except by the feeble energies of the aborigines, it is a duty incumbent on the existing geological survey to make known thoroughly all the facts that pertain to the history and geology and improved methods of this industry.

Sketch of what the earlier Minnesota reports have said. It has been one of the objects of the survey, in the prosecution of the study of the crystalline rocks, to furnish from year to year, whatever information there was that was reliable, relating to the progress of the iron industry in the state. In the seventh, ninth, tenth, eleventh, thirteenth, fifteenth, sixteenth, seventeenth and eighteenth annual reports such fragmentary information is presented.

In the seventh report (for 1878) is given a short account of the Mesabi iron range, the rocks of which are stated to be the downward graduation of those that furnish the silver ores at Thunder bay. Two chemical analyses are given, showing the usual characteristics of those ores. The ore here included is mainly in the form of magnetic oxide, from towns 59 and 60, range 14, and is shown to be a non-titanic Bessemer ore.

The ninth report gives some details of field-observations at the same place at which the samples were obtained, which were analyzed (as above) for the seventh report (pp. 107-109). This report also contains a sketch and map of the Prairie River falls, where the same kind of ore is found, being, indeed, in the westward extension of the same strata. (Compare pp. 196-198).

The tenth report gives no special facts relating to the iron ores, but calls attention (pp. 7-8) to some general considerations touching the prospective importance of this industry to the state of Minnesota, in the following words:

"The report of the survey for 1878 called attention to the existence of iron ore in the northern part of the state in large quantities, and to the fact that parties interested in iron from eastern states have made costly surveys and examinations, attesting the value of these deposits by field-exploration and by laboratory assay. Since then others have become interested in the same way, and it is not premature to predict that the iron ores of Minnesota will, not many years hence, be largely wrought, and yield to the state a revenue which will be commensurate with the extent of the deposits and the importance of such industry. It would be well if the capitalists of Minnesota would look after this matter, and by concerted action retain within the state as much as

possible of the profits of such development of these ores. The blast furnace which is now in operation at Duluth, using ores from Marquette, should be supplied from Minnesota, and Minnesota railroad companies should see to it that these ores are made accessible. Our iron ores are the furthest west of all the lake Superior deposits, and, being in the midst of timbered lands, are situated favorably for reduction by charcoal; while the great region west and northwest, destitute of the rocks producing these ores, will always have to depend on us for iron and its products in the same manner as for lumber. Eastern iron deposits, and eastern furnaces, should not be allowed to find it profitable to send their products past our doors when we have every requisite and every facility for producing the same. It would be a thing highly creditable to the regents, and to the university, to be directly instrumental in developing this great industry, and I hope that general attention may be called to its feasibility.

The eleventh report (for 1882) contains Prof. A. H. Chester's paper on the Minnesota iron districts, and a note by the writer on the age of the rocks of the Mesabi and Vermilion iron districts. The former announces the results of field and laboratory researches that were made for the Minnesota Iron Company prior to their entering upon the systematic and extensive exploitation of the ores of the state which has marked the past few years, and will always be considered as the initial and most important step in their development.

In the thirteenth report is a succinct account of the results of the first year's mining by the Minnesota Iron Company, with a description of the various openings made near Vermilion lake, embracing numerous chemical analyses of the ore.

The fifteenth report is taken up very largely with the geology of the iron bearing rocks, giving the detailed field-observations made in the season of 1886, with a colored geological map of the region, extending from Vermilion lake to Pigeon point. It also has a more detailed map of the region of Vermilion lake.

The sixteenth report is similar to the fifteenth, but its scope is less restricted. It has a geological map of that part of the state between the Rainy river and the headwaters of the Mississippi, and embraces comparative observations on the original Huronian, north of lake Huron, and on the iron-bearing rocks at Marquette, Negaunee and on the Gogebic iron range in Michigan, as well as the Penokee region in Wisconsin.

The seventeenth report consists of further detailed field-observations made along the iron ranges of northern Minnesota, and a summarized review of the work of the survey on the crystalline rocks of the state, giving some idea of the resultant classification and probable stratification.

The eighteenth report embraces the field-observations of N. H.

Winchell in 1888 and 1889. These were made in the iron regions east from Pokegama falls, on the west end of the Mesabi range, and in the region about Tower and Ely. It also embraces some notes made on the crystalline rocks, in the Minnesota valley, and in the region of the typical Huronian. The studies in the field, in 1889, were calculated to supplement the field-notes of former seasons, and were made, in many cases, on the same rocks at the same points, with a view to arrive at the solution of some of the problems that had arisen, and particularly as to the origin of the jaspilite and iron ore. Some of the facts on which the conclusions of this bulletin are based are there given in more detail and with illustrations of the field relations more full than in the bulletin itself.

Another portion of the eighteenth report presents a conspectus of the progress of opinion among American geologists on the origins and classifications of the crystalline rocks, from the earliest observations to the present time, by Alexander Winchell.

Accompanying these field observations, and enumerated in the corresponding pages of the several reports, numerous rock-samples were collected. So far as any descriptions of rocks, ores or minerals are given in this bulletin the same numbers for designating them are employed as in the annual reports, and the reader is referred to these reports for more details of the field relations. A list of all the rock-samples referred to in this bulletin, and the localities where they were obtained, will be found in Appendix D. p. 420.

(1.) THE MAGNETITES OF THE VERMILION SCHISTS.

The existence of merchantable iron ore in the crystalline schists within the limits of Minnesota, was definitely ascertained in the season of 1889, when opportunity was afforded of visiting an ore deposit north of Long lake. This ore had been reported to exist in that neighborhood two years before, and one of the parties of the survey had made search for it, but being without guide acquainted with the region, it failed to find the ore, and its existence was considered one of the many ill-considered rumors that are constantly being started and repeated concerning the discovery of iron ore. The location is lots 4 and 5, sec. 4, and lots 4 and 5,

sec. 5, 63-12, and it was through the aid of Mr. John Mallmann and Mr. E. C. Hillbery that samples of the ore were procured. The country rock is represented by 417 (H) and 418 (H).

By reference to the sixteenth report, page 112, it may be seen that a magnetic ore at the north end of White Iron lake was referred to the Vermilion age in 1887, that then being pronounced "the only known iron ore locality in the rocks of that age." The ore here has not been regarded of sufficient value to work, but there was formerly some cutting into the perpendicular quartzose schists for silver, from which the place was known as *Silver City*. More important discoveries of valuable deposits of iron ore near this place have been reported since.

(A.) *Nature of the Enclosing Rocks.*

(1). *Macroscopic.*—These magnetites are embraced in the mica-hornblende schists, or crystalline schists, which constitute the formation lying next above the granite or gneiss of the Laurentian. The rocks contained in this series are various, in some respects, yet they sustain a constancy in lithological *ensemble* which distinguishes them, in nearly all places, from the next overlying (Keewatin) series. Their prevailing colors are dark, sometimes nearly black, shading to dark green when they become massive. Only in limited areas and much weathered, or decayed, conditions does this dark green fade into a lighter green. In connection with the minerals that give these dark colors, (mica, hornblende, magnetite) will be found, in nearly all cases, a percentage of free quartz. When this is abundant enough to make itself seen in distinct layers or deposits, it is very fine grained, resembling the granular jaspilite of the Keewatin rocks, but on account of the exceeding fineness of both the quartz and the mica, and because generally the quartz is not in distinct and isolated layers or deposits, very much of the rock embracing this ore becomes a magnetitic and micaceo-hornblendic dark quartz schist, shading from light gray to purple and black as the proportions of the minerals vary. Much of it is not magnetic appreciably. A very evident sedimentary structure is thus brought out, the quartzose laminæ being from an inch or a quarter of an inch thick to less than a thirty-second part of an inch, and in some cases almost disappearing because of the uniform dissemination of the darker minerals. This phase is represented by the schists at the north end of White Iron lake.

There is, however, another phase of this iron-bearing rock. It is dark-colored, but greenish, massive and more coarsely crystalline. The magnetite crystals are abundantly scattered through the rock,

increasing in such a degree that the rock becomes the ore. Yet in the purest parts of the ore may be seen hornblendic and micaceous masses, giving a greenish, sometimes a mottled aspect. The rock is hard and the surface is hilly and not at all attractive to the explorer. This latter condition exemplifies the supposed igneous characters of the Vermilion series, but these are found sometimes to gradually fade out and a sedimentary lamination to supervene. Sometimes, however, this massive condition is seen to be abruptly replaced, unconformably, by distinctly quartzose and micaceous schists. Cinnamon garnet frequently accompanies both the schists and the massive rock in the neighborhood of such transitions. This massive rock seldom contains quartz in noticeable amount, and indeed in nearly all cases it appears to be wanting, unless it be of subsequent (secondary) deposition.

Rocks 950, 951 and 1446, illustrate these schists at the north end of White Iron lake.* Rocks 417 (H) and 418 (H) are from this dark and massive phase north of Long lake.

(2) *Microscopic.* We have had the assistance of Dr. H. Hensoldt, of the Columbia College School of Mines, in the preparation of the descriptions of the microscopic characters. The slides were made in the survey laboratory either by us or by Mr. O. W. Oestlund, and the illustrations seen on the microscopic plates have been prepared by us. They are such as will illustrate the descriptions. The numbers attached to the specimens in the field are the same as those employed in these pages. The microscopic characters of the Vermilion schists are illustrated on plate v, figs 1, 2 and 3, which are drawings from Nos. 417 (H), 418 (H) and 1446 respectively.

Rock 417 (H). This rock (see plate v, fig 1) is essentially composed of hornblende and labradorite and must, therefore, be classed among the diorites. In its microscopical structure it closely resembles some of the intrusive coarse-grained diorites of Essex county, Massachusetts, examined by the writer for the Peabody Academy of Science at Salem, in 1888. In its unweathered condition the rock is dark-gray, with a tinge of green; weathered surfaces appear as if daubed with innumerable specks of a whitish paint, these latter having resulted from a complete kaolinization of the labradorite crystals. Hornblende and labradorite are present in about equal proportions. The hornblende scales are full of the

*Dr. M. E. Wadsworth's specimens from this locality, so far as they illustrate the schist, are numbered 1111-1115, 1122-25, 1127. Those of A. Winchell are numbered 100-103 and 980-987. Of the collections of H. V. Winchell, No. 543 (H) is a sample of the ore from the north side of Long lake, and Nos. 417 (H) and 418 (H) illustrate the country rock north of Long lake.

usual cracks and fissures, and are but slightly affected by decomposition along the marginal portions, where minute fibres are observable, indicating a transition into chlorite or epidote. In color the hornblende presents three shades of green, according to whether a scale is cut parallel, or nearly so, to an axis of greatest, medium or least elasticity* and the scales are remarkably free from enclosures. If tested with the lower Nicol (polarizer) only an intense pleochroism is noticed. The labradorite occurs in the shape of crystals and granular masses, which were doubtless originally colorless and transparent, but which are now more or less turbid and clouded by kaolinization. Some pellucid crystals are still to be noticed, and these show between crossed Nicols the characteristic twin-striation. A faint twin-lamellation is also manifested by many of the clouded crystals, which have not yet been completely metamorphosed by kaolinization. A few brownish scales, free from cracks and bounded by parallel lines, indicate the presence of biotite as a minor accessory. They can be easily distinguished from the hornblende by their form, color and pleochroism, which is even more intense than that of the amphibole. Small grains of magnetite are sparingly distributed over the field; they are in many instances surrounded by a brownish decomposition zone.

Rock 418 (H), (see plate v. fig. 2). A rock of practically the same composition as the foregoing (No. 417 H), from which it differs only structurally. It is however more compact and fine-grained, and shows an almost schistose arrangement of the hornblende and feldspar constituents, so that it might, not incorrectly, be termed a hornblende-schist. The hornblende is darker, and even more pleochroic, than is 417 (H); it contains numerous roundish enclosures of a colorless, isotropic substance, possibly a kind of glass. (Glass enclosures are of common occurrence in the hornblende of nearly all crystalline schists.) Such of the labradorite crystals as are not completely kaolinized, show twin-striation, and in many instances the smaller grains have been replaced by secondary quartz. Not a trace of quartz could be observed in 417(H) and from this circumstance, as well as the complete absence of biotite in our present rock, the writer would conclude that 418(H) either represents a more ancient type of the same diorite or that the modifications which it presents are referable to local differences in the conditions which prevailed during the ages of metamorphism, such as heat-pressure or the effects of contact with contiguous rock-masses

*Sections parallel to *a* are of a light yellowish green color. Sections parallel to *b* show a brownish green tint, while those which approximate to *c* are uniformly dark-green, almost bluish.

This rock, which partakes more of the character of a hornblende-schist, affords an instructive example of the manner in which an "orthodox" dioryte may be transformed into a schistose rock by changes comparatively slight, and if we can follow such a rock till it assumes a still more schistose, dense or comminuted character till it passes into a regular slate, many of our present petrographical terms and conceptions will require overhauling.

Rock 1446. A greenish-gray, compact rock (see plate v. fig. 3) exceedingly hard and dense, like basanite, which shows an almost vitreous fracture and which, judging from its megascopical aspect alone, one might well call an aphanitic quartzite.

The microscope, however, shows it to be composed of innumerable layers of silica originally deposited in an amorphous condition, in the manner described in No. 867 (see Jaspilyte) but now simulating hexagonal quartz crystals. These layers are closely interbedded with minute, elongated greenish scales, of a mineral which was, doubtless, once hornblende, but which has been completely transformed into fibrous epidote.* It is this mineral which causes the greenish appearance of the rock, as without it the latter would merely present a uniform tint of gray. In addition to the layers of silica and epidote the rock contains a considerable quantity of magnetite, which is distributed in the shape of opaque grains and crystals, showing cubical and trigonal faces. Some of the magnetite layers consist of much coarser crystals than the others and the silica interposed between these crystals is remarkably clear and polarizes in lively tints, yet the joined globules or hexagons usually show several colors, with a marginal zone, and are totally devoid of fluid-cavities, which clearly indicates their chemical origin. The epidote scales are very evenly distributed and although some of them are much larger than others, yet, on the whole, they are characterized by considerable uniformity in size, shape and color. A "half-inch" objective shows each scale to be a mere aggregate of fibres, like a bunch of straw, and this may be still better observed in sections cut parallel to the plane of stratification.

(3). *Structural features.*—Structurally this ore in its first phase above bears a close resemblance, in its relations to the enclosing rock, to the hematites of the Keewatin series. Its lamination with thin siliceous bands, and its giving place, in various degrees of diminution, to more or less siliceous, parallel, generally contorted sheets, some of which approach pure silica, is quite identical with the behavior of the hematites that accompany the jaspilyte of the Keewatin. This structure is exemplified by the deposit at the

rapids from White Iron lake to Garden lake. The perpendicular attitude of the beds is also like that of the Keewatin lodes.

There is, however, so far as known, no Keewatin counterpart for the structural features that are exhibited by the Vermilion magnetites seen north of Long lake. Here the ore is apparently a primary constituent of a massive rock, the associated minerals and the non-titaniferous character of the ore alone showing its alliance with the Vermilion rocks, rather than with the magnetitic gabbro of the Mesabi range. The structure here has not been fully examined by the survey, and the foregoing statement is based on a general knowledge of the country rock in the region, and on samples that have been furnished by Mr. Mallmann. There may be here also a bedded structure that would appear on making a full examination. But taking the facts so far as they are known it may be said that, north of Long lake, this ore is apparently embraced in a massive eruptive rock in somewhat similar manner as the titaniferous ore is embraced in the gabbro.

(b.) *Qualities of the Vermilion Magnetites.*

(1). *Chemical, etc.* This ore was analyzed by Prof J. A. Dodge, of the University of Minnesota, the specimen being one obtained from Mr. Mallmann—No. 543 (H)—with the following result:

ANALYSIS OF THE VERMILION MAGNETITES.

Silica, SiO_2	10.90
Alumina, Al_2O_3	5.83
Sesquioxide of iron, Fe_2O_3	70.39
Protoxide of iron, FeO	8.75
Lime, CaO	1.20
Magnesia, MgO	1.50
Sulphur, S}.....	.47
Phosphorus, P}.....	.022
Manganese, Mn	none
Titanium.....	none
	<hr/>
	99.062
Metallic iron.....	56.08

This shows a Bessemer ore, though not one of very high rank in metallic iron. The absence of titanium indicates that the rock, at least the ore here analyzed, is not in an original eruptive state, but that the ocean had acted on the sediments, whether of eruptive origin or not, sufficiently long to decompose and extract it (if ever present) prior to the present crystalline condition of the rocks.

(2). *Origin of the Vermilion magnetites.* It seems to be necessary to consider these ores as having at least two different methods of deposition or origination. This inquiry goes no further.

er back than to include their condition immediately before their taking that which they now have; for it is evident that iron can be traced through many changes, mechanical and chemical, due to the vicissitudes of geological history, and that each change might be considered the resultant of forces that preceded, and also the participating cause of those that followed. The ultimate terrestrial source for all superficial iron deposits, whether native or in the form of chemical compounds, may be accepted, for our present purposes, to have been the central molten portions of the globe, according to prevalent accepted deductions* from physical and mathematical laws, and from the more recent observations of Nordenskjöld on the iron-sheeted basalts of Disco island. Appearing as metallic iron, it has gone through such transformations as its chemical and physical environments have made necessary. Sometimes it has maintained the condition it assumed early in its history, and at other times it has been subjected to numerous transformations and chemical combinations. The ores that are found in the later strata of the earth's crust have a more complicated history, and more diverse origins, than those contained in the Archean rocks.

The Vermilion ores † are believed to be the result of hydrothermal forces, acting at considerable depths within the earth's crust, on sediments and on eruptive rocks, and on iron ores that were at first nearly or exactly like the rocks and ores of the Keewatin series, which next succeeds the Vermilion series. It will be proper, therefore, to consider the methods of their earlier deposition as Keewatin constituents, at a later stage in the progress of this report, and to discuss here, briefly, only the manner and cause of their having their present condition. It will not even be necessary to enter on the geological evidence that these ores were formerly in the condition of Keewatin ores. We shall assume that, at present, and shall only call attention to the manner in which they have probably been converted to magnetites, and the enclosing schists to crystalline schists.

In order that there may take place in a rock-mass of any mineral composition, a slow metasomatic change converting it into a different mineral composition, there must be some predisposing causes acting on a favorable conjunction of mineral conditions, and those causes must be brought into activity and maintained

*See Volcanoes, J. W. Judd. pp. 318-322. The theory seems to have originated with Sir Humphrey Davy. See "Iron Manufacturer's Guide," Lesley, p. 357. Principles of Geology; Lyell. Vol. ii, p. 229. (11th Ed. 1872), Phil. Trans. 1828, 244.

† The term Vermilion here, applies to the Vermilion series not to the "Vermilion iron range."

during long periods of time. This problem is resolved, therefore, into an inquiry for these causes and conditions.

The general characteristic nature of the rocks of the Keewatin series has been stated by Dr. Geo. M. Dawson, * Dr. Andrew C. Lawson, † and by the writers.‡ But the actual petrographic characters have been more carefully investigated and published in the late report of Dr. Lawson on the region of Rainy lake. || In general it is agreed by nearly all who have examined them, whether in the field or in the laboratory, that they are characteristically composed largely of materials that had, at first, an eruptive origin, although they exhibit very generally a stratiform arrangement that can be attributed only to the action of oceanic sedimentation. They vary from very evidently eruptive, almost non-quartziferous, basic materials to very siliceous schists. But in all cases they contain a common element, a chlorito-sericitic paste. This paste or typical character sometimes appears much like talc, and in others it is apparently serpentinous; but the general term sericitic, or hydro-micaceous, is usually applicable. The individual, characteristic minerals that are embraced in the Keewatin rocks, so far as it is necessary to consider them in this inquiry, may be reduced to four, viz: 1. A chloritic mineral. 2. A sericitic mineral. 3. A feldspathic mineral (generally plagioclastic.) 4. Quartz.

These make up, in their varied proportions, in their various states of alteration, and in their varied structural positions, the great bulk of the Keewatin stratiform rocks. The non-stratiform consist of such as are easily reducible to these by the action of oceanic levigation and distribution. That is, in the massive greenstones of the Keewatin are found prominently augite and hornblende, in addition to the foregoing. The iron ores, whether magnetic or hematitic (generally the latter) constitute, in limited areas, an important constituent, but they will be considered under a separate head. The various secondary minerals, calcite, epidote, limonite, pyrite, vitreous quartz, siderite, need not be embraced in an enumeration of the principal rock-forming minerals of the Keewatin.

*Geology and Resources of the region of the vicinity of the forty-ninth parallel; 1875, p. 52.

†Report on the geology of the Lake of the Woods region, with special reference to the Keewatin (Huronian?) belt of the Archean rocks. Geol. Nat. Hist. Sur. Can. Vol. 1. New Series. 1885. Report C C.

‡Minnesota survey report for 1886, pp 220-222; ditto for 1888, pp. 38, 132; Am. Geologist, Vol. iii, p. 18.

||Report on the geology of the Rainy lake region. Geol. Sur. Can. Rep. for 1887. F. pp. 57-99. It should be noted, however, that Dr. Lawson includes under the term Keewatin most of the crystalline schists which in this report are styled Vermilion schists. His "Coutchiching series" is also apparently the same as the mica-schists of the Vermilion.

These minerals, it will be seen, would naturally constitute a rather easily disintegrated rock, and also one through which the metamorphosing forces would be quick to send their agents of metasomatic change. Sometimes felsyte has been mentioned in the field-descriptions, but this is an unhappy, even incorrect use of the term. The rock that has been so designated has been, in nearly all cases, a light-greenish, aphanitic, coarsely schistose, scarcely quartziferous rock that is rather soft and intimately related to the sericitic and serpentinous portions. It seems to be about what has been named porodyte by M. E. Wadsworth.* The firmest rocks that appear in the Keewatin are crystalline granitoid masses, also porphyries, which are of isolated and rare occurrence, apparently the result of fusion and intrusive flowage from some of the strata of the Keewatin itself. The greenstones are intermediate, in hardness and endurance, between the porphyritic and and granitoid bosses, and the sericitic schists.

The general characteristic nature of the rocks of the Vermilion series is also well known, and has been stated by different observers. The rocks are essentially micaceous and hornblendic schists, generally showing a sedimentary stratiform arrangement. They also pass into massive greenstones whose composition and manner of occurrence have not been observed to differ from the composition and manner of occurrence of the greenstones of the Keewatin. They are firmer, as a class, than the schists of the Keewatin. They are invaded by granitoid masses of larger area, of more frequent occurrence and of more crystalline character. They change in other places to gneiss gradually in their lower portions, and to the sericitic and chloritic schists of the Keewatin gradually in their upper portions. Sometimes also along their strike, the siliceous element increases or fades out.

The individual minerals that make up the bulk of the Vermilion series, irrespective of the smaller variations and of secondary products, may be put under four heads, viz.: 1. A hornblendic mineral. 2. A micaceous mineral. 3. A feldspathic mineral, (frequently orthoclastic) and 4. Quartz. There are augitic constituents, also olivinitic, in the massive greenstone areas, but they are reducible either to hornblendic or micaceous, and do not play any independent role as minerals and may be disregarded in this comparison. These minerals are so distributed through the Vermilion that the rocks they compose are sometimes dark colored and basic, and sometimes exceedingly siliceous.

The iron ores that are found in the Vermilion, in Minnesota, are

*Bull. Mus. Comp. Zool., V, 280; VII, 60.

magnetic in all known instances. They are sometimes in the schists and sometimes apparently in the massive greenstones. If the Keewatin petrographic characters, as above enumerated, now be compared with the Vermilion, after cancelling like elements, there will be found remaining these differences.

<i>On the part of the Keewatin.</i>	<i>On the part of the Vermilion.</i>
A chloritic mineral.	A hornblendic mineral.
A sericitic mineral.	A micaceous mineral.
A feldspathic mineral (generally plagioclastic.)	A feldspathic mineral (frequently orthoclastic.)
Hematite iron ore.	Magnetite iron ore.

The exact mineral differences. It will be necessary next to examine more closely into these differences, in order to ascertain whether, as supposed, the above different characters as exemplified in the Keewatin are convertible, under the action of any powerful, known, long-continued metamorphosing cause, into those characters that distinguish the Vermilion. It will be found, when the origination of the Keewatin sediments is considered, that the chloritic and sericitic characters are supposed to have been derived from the action of hot, alkaline oceanic waters on the minerals that constituted the lavas and other ejecta from the Keewatin volcanic vents. We have no better evidence of what those minerals were than what we may infer from an examination of volcanic matter of later ages, and even of the present time. The basic dolerites which may be supposed to be derived from the deeper portions, probably from below the crust of the earth, consist essentially of augite (a form of pyroxene closely related to hornblende), biotite, or black mica, plagioclase and magnetite. An occasional small amount of free quartz need not be considered. The minerals of this group are closely allied to those that distinguish, above, the Vermilion rocks from the Keewatin. In other words, the supposed change in the Keewatin minerals, which is to be effected to convert their distinctive characters into those of the Vermilion distinctive minerals, is one that is to bring them into closer resemblance to those from which they are at first supposed to have been derived.

The conversion of the Keewatin chloritic mineral into the Vermilion hornblendic. Is it a possible and natural process to change chlorite to hornblende?

The reverse, or the conversion of hornblende to chlorite, is a well-known and wide-spread change which the microscopic lithologist frequently encounters. It is one of the changes to which erup-

tive basic rocks are specially liable, and the most common cause of their prevailing greenish color.

Chlorite is a compound of magnesia, iron, alumina, water and silica, the magnesia averaging about 34 per cent. and the water over twelve.* It is decomposed by hydrochloric acid, forming a jelly, and is completely soluble in hot sulphuric acid.

Hornblende differs from this in having about 12 per cent. of lime and no water. There are varieties of hornblende that contain some soda, or potash, or manganese, but they bear an insignificant ratio to the great mass of hornblende. The metamorphosing force, therefore, which may convert chlorite to hornblende must be such that it can supply this percentage of lime and remove about the same amount of water. Along with this process the molecular and crystalline structure must be converted from a monoclinic crystallization to a supposed hexagonal one.†

It is perhaps impossible, in the present condition of knowledge respecting the reconversion of secondary minerals back to their originals, to show unqualifiedly the actual steps and the certainty of the change here suggested from chlorite to hornblende. To show that it is possible, and that under conditions that may be plausibly supposed to have obtained, it is probable, is as far as we may be able to go. This change has been suggested by Dr. Lawson (Report on Rainy lake, p. 80.) in the following statement: "The darker, harder, more compact, often glistening hornblende schists appear to be in part an altered phase of the fissile green schists."

It will be noticed, again, that the change from chlorite to hornblende, consisting in the acquirement of lime and the expulsion of water, brings about such an approach toward the composition of originally eruptive augite, that it illustrates the nature of the general alteration that has been alluded to, and suggests the application of heat acting in conjunction with water, during a long period of time, at greater or less depths within the earth's crust.

It is necessary to find some reason for the loss of water and the supply of lime, and perhaps also a small amount of magnesia, to the hornblende, for in that interchange between lime and water consists the essential difference between the chloritic element of the Keewatin schists and the hornblendic element of the Vermilion schists.

At this point it is interesting to note that a frequent secondary

* The study of rocks. Rutley, p. 136.

† Authorities differ as to the crystalline system of chlorite. Apparently some varieties are monoclinic and some hexagonal.

mineral in the Keewatin schists, which has not yet been mentioned, is calcite; occasionally it is dolomitic. It appears not only as disseminated, often microscopic, grains among the sericitic and chloritic scales, causing a slight effervescence in hydrochloric acid, and as amygdulæ in some of the vesicular greenstones*, but sometimes considerable masses of so-called limestone, or marble, are met with. These constitute lenticular masses of considerable dimensions.† The existence of this lime, at least in the form of disseminated grains, has been assigned correctly to the degradational change in the original crystalline rocks which is here inferred, and is thus spoken of by Dr. J. P. Kimball:‡ “The presence of carbonate of lime in many of the schistose rocks of this region must be regarded as generally due to the decomposition of silicate of lime in the silicates of the primary crystalline sediments, whence they were derived.” We have here the needed element. It is intimately present in the schists. It is necessary yet to find a force that can drive off the water and carbonic acid, and allow, or compel the union of the lime with the silicate from which it came.

It has already been intimated that this force was heat encroaching slowly, and through long periods acting on these fissile schists. But before considering its source and its cause, it may be best to inquire whether the other differences that have been noted between the Keewatin and the Vermilion schists may be reduced to the same elements.

The conversion of the Keewatin sericitic mineral to the Vermilion micaceous mineral. The sericites of the Keewatin are its characteristic minerals. They have given the name *sericitic schists* to these rocks in all of the Minnesota reports. This prevailing, omnipresent element has been designated “Keewatin stuff,”|| and it pervades those parts that are fissile and those that are firm. It is equally characteristic in Michigan and Wisconsin as well as in Canada. It may be divided, on chemical distinctions, into various mineral species, but their general resemblance, both in composition and in crystalline structure, as well as physical and geological associations, warrants us in considering them as a whole under one term. Sericite, damourite, paragonite, talc, serpentine, all of which may be paramorphic products of change from muscovite and biotite, or sometimes from hornblende and olivine, are here included. They are hydrated, very fine fibro-laminate-grained, and have a

*Seventeenth Minnesota report, p. 98; Fifteenth report, p. 95.

†Tenth report, p. 91, (Rock Nos. 743 and 746); Eleventh report, p. 165; Fifteenth report, pp. 237, 371, 94-95; Sixteenth report, pp. 95, 317.

‡The iron ores of Marquette, Am. Jour. Sci. May, 1865. Vol. xxxix, p. 303.

||A. Winchell. Minnesota sixteenth report, pp. 310, 312, 343.

larger percentage of magnesia (when not replaced by iron, alumina or soda) and a smaller percentage of potash, than muscovite and biotite. The scales are light-colored, flexible but hardly elastic.

The micaceous mineral that prevails in the Vermilion series of schists is biotite, but muscovite largely replaces it in many situations, particularly in the typical mica schists, while toward the top it is apparently replaced by some of the hydro-micas, or those that characterize the Keewatin schists.* That is, there is a somewhat gradual transition, stratigraphical and mineralogical, from the typical Keewatin schists to the typical Vermilion schists, and none of the contained minerals evince this more completely than the micas. In the Rainy lake region the same transition takes place, according to Dr. Lawson, between his underlying Couchiching mica schists and the overlying Keewatin. "For the most part the contact of the two series is one of apparent conformity, and there is even a sort of transition from one to the other, observable in many places, where fissile, green, hornblendic and chloritic schists are interbedded with more siliceous and micaceous ones."†

This is the case in every place at which this interval has been observed in northeastern Minnesota. Conglomerates and agglomerates occur at various places, and apparently on different horizons in the Keewatin, as they do also in the Vermilion.

Throughout the typical mica schists of the Vermilion there is a larger amount of quartz than in the typical areas of the Keewatin, and it would be obviously impossible to convert by paramorphic change the constituents of one into those of the other, and preserve in the resultant rock a like proportion of free quartz. It is only in those cases when the Keewatin contains more than the normal amount of silica, that is, in most of the graywackes, that a typical mica schist could be supposed to be its metasomatic equivalent. On the other hand there are basic portions of the Vermilion, situated near the bottom of the formation, which are as poor in free silica as any parts of the Keewatin, and have a hornblendic, even a massive diabasic, aspect and composition.‡ The essential difference between the Vermilion and the Keewatin, touching the foliated mineral which they contain is, therefore, partly one of stratigraphic position in the series, and partly one of chemical composition. Obviously

*Seventeenth Minnesota report, pp. 32, 37, 66.

†Report on the Geology of the Rainy lake region. Part F of the annual report for 1887, p. 38. Canadian Geological Survey. In some places Lawson has inferred local unconformity between the Keewatin and the Couchiching—p. 105.

‡Such have not been included in the Couchiching by Lawson; indeed they are not mentioned by him at all at the horizon of transition from the Laurentian to the Couchiching. He finds such at the base of the Keewatin.

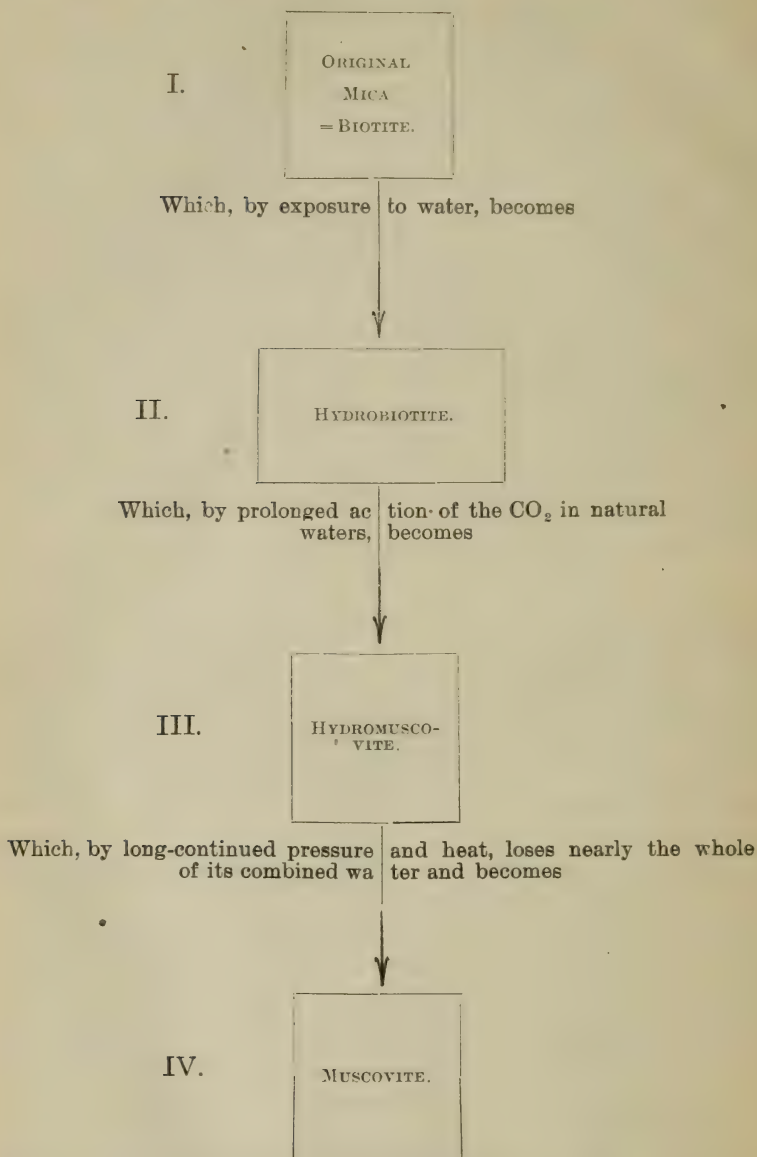
there is no significance in the different stratigraphic order in which this mineral may prevail in the two formations.

The difference which it is necessary to explain on a plausible hypothesis is one that indicates, as with the chlorite and hornblende, a force which will bring the hydro-mica element of the Keewatin back to, or toward, that condition which is near its original. Muscovite and its hydrated variations, are entirely secondary minerals, i. e., they are not found in primary basic eruptive rocks; biotite frequently occurs in such rocks. It is therefore a reasonable supposition that by the re-application of the same agents that gave origin to the primary conditions of these minerals, (i. e., heat, pressure and moisture) they would be restored to their original condition, or at least would show an approximation toward it. The water they had taken up would be expelled and the potash they had lost by oceanic solution would be restored as soon as the water holding it in solution were reapplied with a sufficient degree of heat. Therefore these differences are reducible to the same elements—namely, such that can be destroyed by the application of hydro-thermal action to the sericitic micas of the Keewatin.

[Since the foregoing was written a very interesting discussion of the normal micas has been published by Alexander Johnstone, in the Transactions of the Edinburgh Geological Society, Vol. vi. part I, p. 17. We are gratified that the researches of Mr. Johnstone confirm, essentially, the course of argument employed by us, and lead to such results that they establish not only the natural order of genesis of all the micas, but show that natural causes have produced them all from that which is found (biotite) in original condition in eruptive rocks. He says :

“Seeing that all, or almost all, the micas of the recently formed igneous rocks are of the nature of biotite, which is therefore a product of igneous fusion, and that the micas of the older rocks are referable to the species biotite, hydrobiotite, muscovite and hydromuscovite, we may safely consider the first-named as the original mica, and all the others as being varieties generally derived from it. The experiments which I have already quoted in the first portion of this paper show how the agencies of natural waters, etc., and time are all that is necessary to bring about the various changes in chemical and physical characters essential to the creation of those other varieties of mica. It is not, I think, needful to describe further the processes of evolution of the pale tinted species, as the experiments I have referred to and the following diagram show clearly enough the manner in which I believe the various changes must have taken place :

DIAGRAM OF THE EVOLUTION OF THE MICAS.



NOTE.—The last, by exposure to natural water, can again become hydromuscovite, and then in the same way as III be reconverted into muscovite: hydrobiotite can also go back again into the condition of biotite."

Can the feldspathic (plagioclasic) mineral of the Keewatin be converted to the feldspathic (orthoclasic) mineral of the Vermilion? In other words can the alkaline base potassa or soda be substituted for the alkaline-earth bases of the plagioclase feldspars? Although this distinction between the feldspathic constituents of the two formations is not a sharply marked one (both classes of feldspars being disseminated through them both) yet theoretically those of the graywacke would be expected to be predominantly plagioclasic. This would result from their antecedent origin as minerals of a basic volcanic ejection, and secondarily from the naturally more soluble character of the alkaline bases, by reason of which if potassa and soda were present they would be first extracted by the ocean. Now it is only in the typical quartzose mica schists that orthoclase is found in noticeable amount in the Vermilion series. In the hornblendic schists it is rare, and in the diabasic rocks at the bottom of the series it is apparently wanting, or exists as vein-material. The inquiry pertains, therefore, to the possibility of converting some portion of the alkaline-earth feldspar grains in the graywackes to alkaline feldspar grains of the mica schists. It will be noticed here that the needed change is identical with that which was last mentioned, viz., a substitution of potassa, an alkaline base, for lime or magnesia or some other alkaline-earth base. This difference, therefore, so far as it exists between the two formations, is reducible to the same elements, and can be removed by the same cause, i. e., by the application of heated alkaline solutions while the mineral is under partial or complete hydro-thermal fusion.

The conversion of hematite to magnetite. Magnetite differs from hematite in having a greater ratio of iron to oxygen, and in its crystalline system. Magnetite is found in the primary eruptive basalts where it is one of the essential characteristic minerals. By greater oxidation it is converted to hematite, which is frequent in the metamorphic rocks. When magnetite is found in the metamorphosed rocks it is generally at points and planes of contact with eruptive dikes whose pressure, heat and percolating hot solutions have concentrated the iron from surrounding rock masses. When it constitutes ores in the metamorphic rocks, as in the Vermilion series of schists, it is disseminated either as an ingredient of a massive basic rock, or it is interlaminated with siliceous sheets which are similar to those of "chalcedonic" quartz in the jaspilite of the Keewatin schists. Structurally it repeats the characters of magnetite in the eruptive gabbro, on the one hand, and of the hematites of the Keewatin on the other. It is necessary to con-

sider therefore only the laminated condition, since the massive deposits can be referred directly to dynamic and thermal agents. These laminated deposits of magnetite are embraced, sometimes, in undoubtedly eruptive basic rock.* The change, therefore, from hematite to magnetite, through the action of heat and moisture, seems to be one of the common phenomena of metamorphism, and it is of the same general character as is shown above to have taken place in the other minerals of the Keewatin, viz., it is a step back toward the condition which the constituent iron molecules had when they were erupted with basic lava from the interior of the earth. This difference therefore is reducible to the same elements as those that have already been considered, and may be destroyed by hydro-thermal metamorphism.

Hence all the mineral differences, so far as they play any important role in an inquiry into the possible genesis of the rocks of the Vermilion from those of the Keewatin, are resolvable into the same element, viz., an element that can be caused to disappear by the application of heat and moisture acting through the methods of hydro-thermal metamorphism; and we may not hesitate therefore, to consider the magnetites of the Vermilion schists to have been produced by that means from hematites which were once in the condition of those now mined in the Keewatin schists. This inference will also apply to the rocks that inclose the ores, and it may be said the mica-hornblende schists that are a pronounced feature of the Vermilion series are changed conditions of graywackes and chloritic and sericitic schists similar to those that characterize the Keewatin series. This great change was wrought by the approach toward, if not by the actual invasion of the lower strata by the plane of hydro-thermal fusion, which, according to the researches of Reade, Fisher and Darwin,† must exist near the surface of the earth at a depth which increases from age to age. In the first instance, this alteration must have taken place before the fracturing and crumpling which the Archean rocks now exhibit, by which they have been caused to present, nearly everywhere in Minnesota, sharp and nearly vertical angles of dip, affording exposure of their truncated edges, and it would have produced a shell which may be supposed, under normal conditions, to have encased the globe, consisting of recrystallized sediments. Such shell would be encased in another which, like the crystalline schists, does not exhibit any sign of previous complete fusion but

*American Geologist, Vol. iii, p. 19.

†Compare Claypole's discussions in the *American Geologist* vol. i, p. 382, vol. ii, p. 28 and vol v, p. 83; also Reade *idem*, vol ii, p. 106. and LeConte, *id.* iv. 38.

which has been affected *in situ* by heat, pressure and moisture. Wherever those early sediments were of basic materials the resulting schist-rock is largely hornblendic and biotitic and wherever the soluble silicates had been largely or wholly removed by the oceanic solvent action, leaving in the sediments a preponderance of fragmental quartz derived from earlier Laurentian shores, or when the silica was redeposited by chemical precipitation, the resultant rock is siliceous. Again, it will be seen by this that there can be no general, distinct, sudden line of separation between the crystalline schists and those strata that succeeded them in chronological order. But the crystalline condition would fade out upward into a non-crystalline condition. It would only be where there was bodily transference of fused material, in an intrusive manner, in the heated layers of the crust, or by the eruptions of molten rock from below the earth's crust, that crystalline rock would come into immediate contact with non-crystalline.

(c.) *Probable Parallels in other parts of the United States.*

There are no parallels of the Vermilion ores, (i. e. the ores of the Vermilion series, or crystalline schists,) in Wisconsin, nor in Michigan so far as known. There is a line of strong magnetic attraction running eastward from the Penokee gap, in Wisconsin, and considerable magnetite in the quartz-schists at Black River Falls, but neither of these is believed to belong in so low a horizon as the crystalline schists, but rather to the age of the Animike (Taconic) which marks the extent and direction of the Mesabi range in Minnesota, where, likewise, magnetite accompanies some of the slates of the Taconic.

In New York state, according to the descriptions of C. E. Hall* the magnetic iron ores which are not titaniferous are found in a series of rocks which he considers "lower Laurentian," in distinction from those of the labradorite rocks, or "upper Laurentian." These are quartzytes, hornblendic gneisses, and micaceous garnetiferous gneisses. Their stratigraphic position, as well as their associated lithology, and their chemical qualities, seem to ally them with the magnetites of the Vermilion of northeastern Minnesota. These mines are very important, and have supplied large quantities of the best ores of New York.

In New Jersey, according to the report of Dr. Kitchell, † the magnetic ores are found in a gneissic rock associated with hornblendic and micaceous schists, with which they are interstra-

*Report of the State Geologist of New York for 1884, pp. 23-34, 1885; also Thirty-second report of the New York State Cabinet, Albany.

† Annual report on the Geological survey for 1856, as quoted by Prof. Geo. H. Cook in *Geology of New Jersey*, 1868, p. 533.

tified. They are considered to be in the Azoic formation. According to the special descriptions many of the New Jersey mines appear to have wall-rocks of hornblende or hornblendic schist. Their chemical characters also resemble those of the magnetites of the Vermilion series in Minnesota.

In Pennsylvania, as described by Dr. Persifor Frazer, and by Mr. D'Invilliers, in Berks and Chester counties, nearly all the magnetic iron deposits (except those of the Mesozoic) are in gneiss or crystalline schists, in which they constitute *sedimentary* beds interstratified with the country rock. (Second Geological survey of Pennsylvania. Reports C₄ and D₃).

In North Carolina that series of schists and gneisses in which is situated the great Cranberry ore bank, in Mitchell county, compares both in the nature of the rocks and in the character of the ore, with the schists of the Vermilion. This belt of mica schists and hornblendic schists, associated with and blending into dark gneisses, extends apparently from Canada to Georgia, and in numerous places it is characterized by such magnetites. It is quite likely therefore that in the Northwest this horizon of iron will in the future become more productive, and perhaps will furnish some of the most valuable mines.

(2) THE HEMATITES OF THE KEEWATIN SCHISTS.— (*The Vermilion range*).

These hematites are the basis of all the actual mining that has yet been done in the state. They are therefore the most important of the deposits considered in this report. They supplied in 1839, 844,638 tons of Bessemer ore, and the total shipment from the Minnesota mines since 1884, when the first ore was sent from Tower, to the close of 1890, reaches 3,227,347 tons.

(a) *Nature of the Enclosing Rocks.*

While the rocks of the Keewatin series exhibit a wide range of characters, extending, in structure, from the most important of most massive, and in quality from the most basic to the most acidic, there is one character that pervades them all, and serves as a distinguishing stamp of a common lineage—a chloritic or hydro-micaceous element which gives them generally a greenish tinge when the chlorite prevails, and a silky sericitic luster and a smooth "tal-cose" feel in the hand, when the sericitic mineral is abundant.

This element is sometimes screened by an incipient re-crystallization, and indeed it is lost entirely by local fusion, and intrusion of the molten rock among the adjoining schists. The former has taken place extensively near the bottom of the Keewatin schists, where they gradually assume the characters of the mica schists, or the Vermilion series underlying, and the latter has been observed on a small scale at some points near Tower.* On the upper waters of the Kawishiwi river the graywacke also becomes sub-crystalline *in situ*, making a massive, granitoid, red-weathering rock, approaching syenite. In the Giant's range of hills, about 15 miles south of Tower, such fused portions of the Keewatin seem to have been the source of the syenite rock of the hills, and the protrusion of this fused material was probably due to the intensified southwestern extension of the line of incipient crystallization mentioned on the upper waters of the Kawishiwi.†

Specifically the Keewatin embraces graywacke, argillyte, chlorite schist, "greenstone," a syenite-looking massive rock, sericitic schist, agglomerates, porodyte, porphyritic massive rocks of various kinds, and fragmental conglomerates. Of all these the "greenstone" is that with which we have most to do here, because in all cases the hematites are embraced in it. This greenstone takes on different aspects. It seems to be the same that in Michigan has generally been denominated dioryte. There are many places where it presents the aspect of an original crystalline eruptive rock as at Kawasachong falls, but that is not its most frequent condition, at least in those portions which are seen about the mines. On the contrary it usually appears as an "altered eruptive," and frequently it embraces angular and rounded fragments, large and small, of other rocks such as graywacke, argillyte and greenstone like itself. Such are noticeable at the railroad cut at Ely, and on the southeastern side of Ogishke Muncie lake, where it forms the lower portion of the great Ogishke conglomerate. In numerous instances the greenstone has been seen, as about Frogrock lake, to be striped by sedimentation lines, indicating the action of the ocean in distributing its ingredients.‡

As to the origin of the bulk of the Keewatin sediments, it was volcanic. This has already been stated in describing the Vermil-

*Compare rock samples 868, 868 A and 868 E, 15th Report, p. 267. Also rock samples 1 (H), 15th Report, pp. 315, 316. No. 868 A is illustrated in thin section on plate v.

†Fifteenth report, pp. 347-354.

‡See fifteenth annual report, p. 372; sixteenth report, pp. 95-99, 108, 306, 348. The term "Ogishke conglomerate" has been made to cover, in our opinion, two widely separated conglomeritic formations, viz. (1) the characteristically agglomeritic portions of the Keewatin, about Ogishke Muncie lake, which in their western extension constitute the Stuntz island agglomerate, and (2) the basal conglomeritic portions of the Animike (Taconic), which further east forms the lower slate-conglomerate of the Canadian "Huronian."

ion, and in making a comparison of the Keewatin with the Vermilion. The hot alkaline waters of the Keewatin ocean acted readily on those volcanic ejecta. The silicates were decomposed in part and the insoluble residues were mixed as a siliceous pulp with other grains that were not decomposed. Whenever, and wherever the supply of material from subterranean sources was rapid this decomposition was not completed, and the sediments were simply distributed by the currents and waves in the same manner as clays and sands are now distributed, retaining largely their chemical composition and sometimes even their mineral structures. More or less change was effected, however, in nearly all cases, and the augitic and feldspathic and olivinitic minerals were reduced, by the decoctive action of the water, to chloritic and micaceous elements. If the volcanic supplies waned, or ceased, larger proportionate amounts of free silica were mixed with the more slowly accumulating sediments. This silica was derivable from any pre-existing granitic shores which might be attacked and eroded, or was precipitated from the oceanic waters which must have held in solution a large per cent of that derived from volcanic ejecta which had been decomposed.*

In general, therefore, the structure of the Keewatin rocks, whether they be in the form of graywackes, schists, greenstones or argillites, proves them to have been, in nearly all cases, laid down by the direct action of sedimentary forces, though their mineral character proves the sediments to have been largely of volcanic origin. There are also some massive, apparently originally eruptive portions which have never been disturbed by oceanic distribution since their extrusion from the interior of the earth in Keewatin time.

We have been furnished, by the courtesy of Supt. D. H. Bacon, of the Minnesota Iron Company, with the records of some of the drill-holes made by the company to explore underground the ore-lodes at Tower. Many have been made since these were transcribed, but those which follow show not only the method of the exploration but the physical structure, and especially the frequent alternations in the nature of the enclosing rocks. These records were kept by the superintendents of the drills at different times, Messrs. Prince, Cole and Wilcox, and the descriptive terms are those which they employed. The strata have such positive and evident characters, and generally are so contrasted in lithology that these descriptions may be accepted as correct.

*Compare "On a possible chemical origin of the iron ores of the Keewatin in Northeastern Minnesota." AMERICAN GEOLOGIST. Vol. iv, p. 291.

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole A—[Drilled in 1887]; angle 51°; vertical distance 81 ft; cost \$734.49; average cost \$7.06 per foot.

Marked [. .].

AT THE STONE MINE.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	12		12	0
Jasper.....	12	11	24	11
Red soap rock.....	1	4	26	3
White soap rock....	4	1	30	4
Soap rock.....	2		32	4
Jasper.....	1		33	4
Soap rock.....	3	3	36	7
Jasper.....	3		39	7
Soap rock.....		10	40	5
Jasper.....	14	4	54	9
Soap rock.....	3	1	57	10
Jasper.....	1		58	10
Soap rock.....	8		66	10
Jasper.....		9	67	7
Soap rock.....	2		69	7
Light slates.....	15	8	85	3
White quartz.....	8	1	93	4
Jasper.....		6	93	10
Quartz.....		7	94	5
Soap rock.....	1	5	95	10
Jasper.....	8	4	104	2

Hole B—[Drilled in 1887]; angle 45°; vertical distance 92½ ft.; cost \$724.44; average cost \$5.54 per foot.

Marked ..].

AT THE ELY MINE.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Jasper & mixed rock.	45	6	45	6
Chlorite schist.....	1	5	46	17
Ore.....	3	8	50	7
Quartz.....	1	8	52	3
Chloritic schist (red)	11	1	63	4
Jasper.....	1		64	4
Chloritic schist (red)	2		66	4
Ore.....	6		72	4
Chloritic schist (red)	2		74	4
Ore and 4 in. jasper.	3	10	78	2
Jasper.....	2		80	2
Chloritic schist (red)	3	1	83	3
Chloritic schist.....	12		95	3
Jasper.....	10	10	106	1
Ore.....	3		109	1
Jasper.....	10	7	119	8
Chloritic schist.....	10	1	129	9
Jasper.....	1		130	0

Hole C—[Drilled in 1887]. Angle 45°, vertical distance 284 feet 4.5 inches, cost \$674.88; average cost per ft., \$1.71. Diamonds cost \$315. About 75 paces N. E. ¼ post sec. 26, 62, 15. 1740 ft. E. of E. end of Stuntz pit.

Marked [...].

AT STUNTZ MINE.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Surface.....	7	0	7	0
Copper scales about 20ft.				
Chloritic schists....	395	2	402	2

Hole D—[Drilled Dec. 5, 1887-Jan. 4, 1888;] angle 65°; vertical distance 320 ft. 3 in.; cost, \$1,359.25; average cost per ft., \$3.85. Depth, 353.4ft.

Marked [. . .].

AT ELY MINE (Between Tower and Ely).

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	13	0	13	0
Ore.....	193	9	206	9
Fe. 67.55.....				
P. 158.....				
Si. 110.....				
Soap rock.....	103	11		
Jasper.....	13	4	324	0
Soap rock.....	7		331	0
Jasper.....	0	10	331	10
Soap rock.....	13	0	350	6
Jasper.....			353	4

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole E—[Drilled January 5th, 21st, 1888]; angle $76^{\circ} 45'$; vertical distance, 326 ft. 6 in.; cost \$722.18; average cost per foot, \$2.15.

Marked [. . . .].

AT ELY MINE from same point as D.

Kind of rock.	Thick-	Depth.
	ness.	
	ft. in.	ft. in.
Soap rock.....	20 0	20 0
Ore.....	7 0	27 0
Soap rock.....	20 5	47 5
Jasper.....	23 3	70 8
Soap rock.....	87 4	158 0
Jasper.....	7 0	165 0
Soap rock.....	65 6	230 6
Ore.....	1 0	231 6
Soap rock.....	104 0	335 6

Hole H—[Drilled May 12th–June 30, 1888]; angle $27^{\circ} 30'$; vertical distance 193.9 ft.; direction of hole S.

Marked [. .]

AT ARMSTRONG VEIN.

Kind of rock.	Thick-	Depth.
	ness.	
	ft. in.	ft. in.
Soap rock.....	13 2	.....
Jasper.....	76 2	89 4
Soap rock.....	11 6	100 10
Jasper.....	7 0	107 10
Soap rock.....	11 6	119 4
Jasper.....	46 5	165 9
Soap rock.....	11 5	177 2
Jasper.....	20 6	197 8
Ore.....	10 0	207 8
Jasper.....	83 4	291 0
Soap rock.....	37 10	328 10
Quartz.....	4 0	332 10
Chloritic schist.....	87 4	420 0

Hole F—[Drilled Jan. 31–June 30, 1888]; angle 28° ; vertical distance, 397 ft. 8 in.; direction of hole, N. E. by N.

Marked [.].

AT EAST TOWER DOCK.

Kind of rock.	Thick-	Depth.
	ness.	
	ft. in.	ft. in.
Soap rock.....	75 0	75 0
Jasper.....	3 0	78 0
Soap rock.....	7 0	85 0
Jasper.....	4 0	89 0
Soap rock.....	76 0	165 0
Quartz.....	2 0	167 0
Soap rock.....	54 10	221 10
Jasper.....	6 0	227 10
Soap rock.....	11 0	238 10
Jasper.....	3 0	241 10
Soap rock.....	38 2	280 0
Quartz.....	5 0	285 0
Jasper.....	39 8	324 8
Soap rock.....	4 9	329 5
Jasper.....	2 0	331 5
Soap rock.....	13 0	344 5
Jasper.....	6 2	350 7
Quartz.....	11 9	362 4
Red soap rock.....	56 7	418 11
Ore (Fe 66.71; P. .090 Si. 2.02).....	4 2	423 1
Soap rock.....	28 7	451 8
Jasper.....	8 6	460 2
Soap rock.....	26 0	486 2
Jasper.....	5 0	491 2
Soap rock.....	43 3	534 5
Ore (Fe. 68.9; P. 130 Si. 58).....	38 0	572 5
Soap rock.....	21 9	594 2
Jasper.....	4 8	598 10
Soap rock.....	12 0	610 10
Ore.....	1 6	612 4
Soap rock.....	64 10	677 2
Jasper.....	3 0	680 2
Ore.....	0 6	680 8
Jasper.....	7 4	688 0
Jasper.....	24 11	712 11
Soap rock.....	32 0	744 11
Jasper.....	102 6	847 5

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole M—[Drilled July 28-Aug. 7, 1888]; angle 38°; vertical distance 80. ft. 3 in; direction of hole, south.

Marked [. . .].

AT ARMSTRONG VEIN.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Jasper	9	0	9	0
Soap rock.....	30	4	39	4
Jasper	6	8	46	0
Soap rock.....	15	3	61	3
Jasper	30	10	92	1
*CLAY AND GRAVEL..	9	10	101	11

Hole N—[Drilled Aug. 2-Sept 20, 1888]; angle 45°; vertical distance 716.5 ft; direction of hole, east.

Marked [. . .].

AT GRAVEL PIT, NEAR SECTION HOUSE.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Gravel.....	94	0	94	0
Gray slate.....	426	6	520	6
Quartzite.....	197	10	718	4
White quartzite....	18	2	736	6
Gray slate.....	276	10	1013	4

*Supt. Bacon says it could not have been clay and gravel, but was probably a soft breccia.

Hole K—[Drilled June 29-July 21, 1888]; angle 35°; vertical distance, 100 ft., 8 in.; direction of hole, south.

Marked [. . .]

AT ARMSTRONG VEIN.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	17	0	17	0
Jasper	95	5	112	5
Soap rock	15	0	127	5
Jasper	24	0	152	5
Ore.....	4	2	156	7
Jasper	1	0	157	7
Soap rock.....	2	6	160	1
Jasper	13	4	173	5
Ore.....	2	0	175	5

Hole L—[Drilled July 31-Aug. 11, 1888]; angle 16°; vertical distance. 62 ft., 3 in.; direction of hole, north

Marked [. . .]

AT NORTH LEE STOCK PILE, SAME AS J.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock... ..	35	0	35	0
Jasper	3	0	38	0
Soap rock.....	16	8	54	8
Jasper	4	2	58	10
Soap rock.....	5	0	63	10
Jasper	117	3	181	1
Mixed ore and jasper	31	1	212	2
Jasper	13	10	226	0

Hole I—[Drilled June 1-June 18, 1888]; angle 29°; vertical distance, 157 ft. 6 in.; direction of hole, N.;

Marked [. . .].

AT SOUTH LEE MINE.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	100	4	0	0
Jasper.....	20	0	120	4
Soap rock.....	31	0	151	4
Poor Ore.....	38	0	189	4
Soap rock.....	135	6	324	10

Hole J—[Drilled June, 1888]; angle 30°; vertical distance, 123.5 feet.

Marked [. . .].

AT NORTH LEE STOCK PILE DOCK.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	57		57	
Jasper.....	10		67	
Soap rock.....	22		89	
Jasper.....	63	5	152	5
Ore.....	2	6	154	11
Jasper.....	92	2	247	1

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole X—[Drilled Dec. 7-Dec. 15, 1888]; angle —; vertical distance, —; direction of hole, south.

Marked [. . .].

AT SOUTH LEE VEIN.

Kind of rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Stand pipe	14	0	14	0
Soap rock.....	184	6	198	6
White quartzyte.....	3	7	208	1
White quartzyte and soap rock.....	6	0	208	1
Soap rock.....	52	0	260	1

Hole 2—[Drilled Sept. 27—Dec. 1, 1886.] Angle 60°; vertical distance 303ft. 6in. Direction of hole, south.

AT END OF NO 2, 1st LEVEL BREITUNG.

Kind of Rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Ore and jasper.....	2	0	2	0
Jasper	7	9	9	9
White q'rtz & jasper	4	3	14	0
Jasper	5	0	19	0
Ore	9	19	9	19
Jasper	17	8	37	5
Ore and jasper.....	4	3	41	8
Ore	1	0	42	8
Jasper	15	8	58	4
Soap rock	46	7	104	11
Jasper	1	0	105	11
Ore and jasper.....	3	0	108	11
Jasper	50	3	159	2
Soap rock.....	5	0	164	2
Jasper.....	5	0	169	2
Soap rock.....	19	1	188	3
Jasper	8	5	196	8
Soap rock.....	18	0	214	8
Jasper	2	0	216	8
Soap rock.....	28	7	245	3
Ore and soap rock..	6	0	251	3
Soap rock.....	7	0	258	3
Clean ore.....	10	0	268	3
Soap rock.....	14	0	282	3
Jasper	2	0	284	3
Soap rock.....	34	7	318	10
Jasper.....	4	6	323	4
Soap rock.....	27	2	350	6

Hole Z—[Drilled in 1888]; angle 32°; vertical distance, 342 ft.; direction of hole, north.

Marked [. . .].

AT NO. 3 SHAFT.

Kind of rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Stand pipe.....	18	0	18	0
Soap rock.....	2	5	20	5
Jasper	3	5	23	10
Soap rock.....	28	3	51	8
Soap and paint rock.	38	3	89	11
Soap rock.....	24	6	114	5
Ore.....	6	3	120	8
Paint rock.....	10	6	131	2
Soap rock.....	155	8	286	10
Paint rock.....	2	8	288	10
Soap rock.....	4	4	293	2
Jasper.....	2	0	295	2
Soap rock.....	16	6	311	8
Jasper.....	7	3	318	11
Soap rock.....	16	0	334	11
1st 6 ft. { Fe. 65.10 P. .076 Si. 5.93 Fe. 67.190 P. .098 Si. 1.44	24	0	358	11
Ore, last 10 ft. {				
Paint rock.....	3	0	361	11
Jasper	5	2	367	1
Soap rock.....	4	8	371	9
Jasper	14	1	385	10
Soap rock.....	8	3	394	1
Jasper	3	3	397	4
Soap rock.....	26	11	424	3
Jasper	25	3	449	6
Quartzyte.....	7	0	456	6
Soap rock.....	6	0	462	6
Jasper	26	9	489	3
Soap rock.....	6	0	495	3
Jasper	4	7	499	10
Soap rock.....	8	6	503	4
Jasper	14	8	523	0
Paint rock.....	4	0	527	0
Jasper	4	9	531	9
Ore.....	4	2	535	11
Soap rock.....	10	0	545	11
Jasper	24	5	570	4
Paint rock.....	6	9	577	1
Jasper	0	8	577	9
Ore.....	7	0	584	9
Jasper	2	0	586	9
Ore.....	27	2	613	11
Jasper	1	0	614	11
Paint rock.....	5	8	620	7
Ore.....	17	5	638	0
Ore and jasper.....	7	4	645	4

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole G—[Drilled April 2nd—May 28th, 1888]; angle 36° ; vertical distance 381.8 ft. direction of hole N. Marked [. .]

AT EAST TOWER DOCK.

Hole EE—[Drilled May 8th—June 25, 1889]; angle 27° ; vertical distance 196 ft; 397 ft. N. E. of H hole.

AT ARMSTRONG.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft. in.	
Soap rock.....	63 0		
Jasper	5 6	68 6	
Soap rock.....	11 7	80 1	
Jasper	23 2	103 3	
Soap rock.....	150 2	253 8	
Quartz.....	11 9	265 5	
Soap rock.....	42 0	307 5	
Quartz.....	6 9	314 2	
Jasper	23 2	337 4	
Soap rock.....	13 0	350 4	
Jasper	2 4	352 8	
Soap rock.....	26 10	379 6	
Jasper.....	13 0	393 5	
Soap rock.....	37 10	431 3	
Jasper.....	4 6	435 9	
Soap rock.....	4 5	440 2	
Jasper	9 6	449 8	
Soap rock.....	2 8	452 4	
Ore	0 4	452 8	
Soap rock.....	26 4	479 0	
Jasper	17 4	496 4	
Soap rock.....	6 0	502 4	
Jasper	4 8	506 4	
Soap rock.....	15 0	521 4	
Jasper	7 0	528 4	
Soapstone	35 0	563 4	
Ore.....	47 10	611 2	
Paint rock.....	7	618 2	
Jasper	24	642 2	
Jasper	7 7	649 9	

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft. in.	
Soap rock.....	56 8	56 8	
Jasper	4 0	60 8	
Soap rock.....	24 0	84 8	
Jasper	7 3	91 11	
Paint rock.....	1 10	93 9	
Jasper	34 11	128 8	
Soap rock.....	22 4	151 0	
Jasper	29 3	180 3	
Soap rock.....	17 0	197 3	
Jasper	8 6	205 9	
Soap rock.....	17 8	223 5	
Jasper	36 1	259 6	
Soap rock.....	1 8	261 2	
Jasper	25 11	287 1	
Soap rock.....	30 4	317 5	
Jasper	5 5	322 10	
Ore	9 0	331 10	
Soap rock.....	2 5	334 3	
2nd class ore.....	14 1	348 4	
Ore	5 8	354 0	
Soap rock.....	9 2	363 2	
Quartz and ore....	4 0	367 2	
Ore	6 4	373 6	
Jasper	34 0	407 6	
Ore and Jasper....	7 6	415 0	
Jasper	10 9	425 9	
Quartz.....	1 0	426 9	
Soap rock and paint rock	4 0	430 9	
Jasper	1 0	431 9	

Hole CC—[Drilled April 5th—April 24th, 1889]; angle $10^{\circ} 30'$; vertical distance 41 ft. 4 in.; direction of hole—south. 227 ft. north of west end of Montana pit.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft. in.	
Stand pipe.....	6	6	
Chloritic schist....	42 11	48 11	
Mica schist.....	131 9	180 8	
Jasper.....	51 11	212 7	
Ore.....	14 7	227 2	

Hole DD—[Drilled April 26th—May 13th, 1889]; angle 27° ; vertical distance 125 ft. 3 in; 227 ft. north of east end Montana pit.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft. in.	
Soap rock.....	228 2	228 2	
Paint rock.....	3 11	232 1	
$\left\{ \begin{array}{l} \text{Fe.} = 68.45 \\ \text{P.} = 0.43 \\ \text{Si} = 1.69 \end{array} \right.$			
Ore.....	35 9	267 10	
Soap rock.....	8 0	275 10	

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole T—[Drilled Sept. 26—Dec. 6, 1888]; angle 36°; direction of hole, north; vertical distance, 588.5 feet.

AT STONE SHAFT NO. 3.

Kind of rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Standpipe.....	22	2	22	2
Soap rock.....	280	10	303	0
White quartzite....	3	0	306	0
Jasper.....	1	0	307	0
Soap rock.....	14	6	321	6
Jasper.....	3	4	324	10
Soap rock.....	23	0	347	10
Jasper.....	3	0	350	10
Soap rock.....	11	0	361	10
Jasper.....	5	8	367	6
Soap rock.....	7	8	375	2
Jasper.....	4	0	379	2
Soap rock.....	13	0	392	2
Jasper.....	14	6	406	8
Soap rock.....	21	0	427	8
Jasper.....	30	0	457	8
Soap rock.....	15	2	472	10
Jasper.....	4	0	476	10
Paint rock.....	1	2	478	
10th ft. { Fe. 68.40	29	9	507	9
Ore { P. .055				
19th ft { Si. 1.40				
Fe. 67.85	2	0	509	9
Si. .97				
Paint rock.....	1	0	510	9
Jasper.....	4	0	514	9
Ore.....	7	0	521	9
Ore and jasper.....	45	8	567	5
Jasper.....	19	6	586	11
Soap rock.....	10	1	597	0
Jasper.....	46	7	643	7
Soap rock.....	38	0	681	7
Jasper.....	3	7	685	2
Soap rock.....	3	5	688	7
Jasper.....	312	5	1001	0
Hydro mica schist...				

Hole U—[Drilled Oct. 19th--Nov. 31st, 1888]; angle, 30; vertical distance, 208 ft.; direction of hole, south.

Marked [. . . .].

AT SOUTH LEE MINE.

Kind of rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	74	0	74	0
Soap rock and white quartzite.	10	0	84	9
Soap rock.....	142	0	226	9
Paint rock.....	7	0	233	0
Ore { Fe. 63.18	23	0	248	0
{ P. .045				
{ Si. 6.42				
Paint rock.....	23	0	261	0
Jasper.....	4	5	265	7
Soap rock.....	138	5	404	0

Hole 1—[Drilled Aug. 9—Sept. 23, 1886.] Angle 45°; vertical distance 164.5ft.; direction of hole, east and down.

AT END OF NO. 2, 1st LEVEL BREITUNG.

Kind of Rock.	Thick-ness.		Depth.	
	ft.	in.	ft.	in.
Jasper.....	118	9	118	9
Clean ore.....	2	2	120	11
Mixed ore.....	1	0	121	11
Jasper.....	18	9	140	8
Clean ore.....	1	0	141	8
Mixed ore.....	7	7	142	3
Jasper.....	7	2	149	5
Soap rock.....	10	0	159	5
White quartz.....	6	0	165	5
Soap rock.....	58	8	224	1
Ore and quartz.....	2	1	226	2
Jasper.....	6	6	232	8

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole AA—[Drilled December 16th, 1888 — May 11th, 1889]; angle 21° ; vertical distance 177 ft; started from same point as X.

AT SOUTH LEE VEIN.

Kind of rock.	Thick- ness.	Depth.
	ft. in.	ft. in.
Stand-pipe	14 0	14 0
Soap rock	94 0	108 0
Quartz & soap rock ..	25 0	133 0
Soap rock	61 9	194 9
Jasper	2 2	196 11
Soap rock	22 9	219 8
Jasper	5 5	225 1
Soap rock	52 4	277 5
Jasper	2 9	280 2
Soap rock	11 10	292 0
Jasper	20 3	312 3
Soap rock	94 11	406 2
Quartz & soap rock ..	7 10	415 0
Soap rock	100 0	515 0
Quartz & soap rock..	8 0	523 0

Hole FF—[Drilled May 14th—May 25th, 1889]; angle $43^{\circ} 30'$, vertical distance 185 ft. 2 in.; 227 ft. N. of E. end of Montana pit.

Kind of rock.	Thick- ness.	Depth.
	ft. in.	ft. in.
Soap rock	132 7	132 7
Quartz	2 6	135 1
Soap rock	89 7	224 8
Soap rock	35 10	260 6
Ore { Fe-68.70	8 7	269 1
P-.055		
Si-.75		

Hole 6—[Drilled Nov. 16—Nov. 26, 1887]; angle 50° ; vertical distance 80 ft., 9 inches; direction of hole, north.

AT TOWER MINE, NO. 2 SHAFT, BOTTOM 2D LEVEL.

Kind of rock.	Thick- ness.	Depth.
	ft. in.	ft. in.
Ore	87 5	87 5
MUD	14 0	101 5
Jasper	4 0	105 5

Hole BB—[Drilled March 6th—May 2nd, 1889]; angle $43^{\circ} 30'$; vertical distance 510 ft. 1 in.; direction of hole, north. Drilled on same line as hole Z.

AT NO. 3 SHAFT.

Kind of rock.	Thick- ness.	Depth.
	ft. in.	ft. in.
Stand-pipe	20 0	20 0
Jasper	5 9	25 9
Soap rock	91 7	117 4
Ore	9 0	130 4
Jasper	10 8	141 0
Soap rock	28 3	169 8
Jasper	3 4	173 0
Soap rock	110 2	283 2
White quartz	2 6	285 8
Soap rock	35 6	321 2
White quartz	1 0	322 2
Soap rock	20 2	342 4
Paint rock	12 0	354 2
Ore	6 2	360 2
Jasper	3 0	363 2
Ore	3 11	367 5
White quartz	2 6	369 11
Jasper	1 2	371 1
Ore	15 5	386 6
Jasper	6 1	392 7
Paint rock	2 8	395 3
Jasper	6 11	402 2
Soap rock	1 9	403 11
Jasper	62 7	466 6
Soap rock	4 0	470 6
Jasper	19 2	489 8
Soap rock	3 6	493 2
Jasper	31 3	524 5
Soap rock	3 4	527 9
Jasper	14 5	542 2
Paint rock	3 6	545 8
Ore	7 0	552 8
Soap rock	42 7	595 3
Jasper	3 6	598 9
Paint rock	11 8	610 5
Jasper	1 7	612 0
Ore	14 4	626 4
Soap rock	11 4	637 8
Ore	7 4	645 0
Soap rock	1 10	646 10
Paint rock	0 4	647 2
Ore	0 10	648 0
Jasper	3 0	651 0
Ore	1 0	652 0
Soap rock	7 6	659 6
Jasper	6 8	666 2
Soap rock	74 10	741 0

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole 9—[Drilled Dec. 27-Jan. 22, 1889]; angle 1° , 30 in; vertical distance, 6 ft., 10 in.; direction of hole, south; started from drift on 2d level of No. 7 shaft, 114 ft. from surface, measured on an incline.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Jasper.....	10	6	10	6
Soap rock and jasper.	2	0	12	6
Soap rock.....	10	3	22	9
Jasper.....	16	5	39	2
Soap rock.....	10	0	49	2
Jasper.....	11	8	60	10
Soap rock.....	29	3	90	1
Jasper.....	112	10	202	11
Soap rock.....	20	0	222	11
Jasper.....	20	4	243	3
Soap rock.....	18	2	261	5

Hole 10—[Drilled Jan. 23-Feb. 12, 1889]; angle, 45° ; vertical distance, 154 ft., 3 in.; direction of hole, south; started from same point as No. 9, on second level of No. 7 shaft.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Jasper.....	4		4	
Soap rock.....	4	10	8	10
Jasper.....	6	0	14	10
Soap rock.....	11	0	25	10
Jasper.....	11	6	37	4
Soap rock.....	12	0	49	4
Jasper.....	4	5	53	9
Soap rock.....	14	6	68	3
Jasper and soap rock	9	6	77	9
Soap rock.....	12	0	89	9
Jasper.....	3	0	92	9
Soap rock.....	4	10	97	7
Jasper.....	109	9	207	4
Quartz and jasper..	10	10	218	2

Hole R—[Drilled Sept. 5th—Dec. 15th, 1888]; angle 35° ; vertical distance 259.5 ft; direction of hole north.

Marked [· · ·].

AT SOUTH LEE VEIN.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
White quartzite.....	85	0	85	0
Soap rock.....	166	0	251	0
Quartzite and ore...	27	11	278	11
Jasper.....	7	2	286	1
Quartzite and ore...	17	4	303	5
Jasper.....	1	6	304	11
Quartzite and ore...	35	1	340	0
Quartzite.....	13	0	353	0
Jasper.....	41	10	394	10
Quartzite.....	3	0	397	10
Ore and quartzite..	3	0	400	10
White quartzite....	13	8	414	6
Ore and quartzite..	12	2	426	8
Ore and jasper.....	9	2	435	10
White quartzite....	16	6	452	4

Hole S—[Drilled Sept. 13th—Oct. 30, 1888]; angle 62° ; vertical distance 349.5 ft; direction of hole south.

Marked [· · ·].

AT ARMSTRONG VEIN.

Kind of rock.	Thick- ness.		Depth.	
	ft.	in.	ft.	in.
Soap rock.....	12	0	12	0
Jasper.....	25	5	37	5
Ore and quartzite...	4	8	42	1
Soap rock.....	56	5	98	6
Ore.....	2	6	101	0
Soap rock.....	3	0	104	0
Ore.....	24	0	128	0
Soap rock.....	17	7	146	7
Ore and quartzite...	12	0	157	7
Jasper.....	40	5	198	0
Ore.....	2	6	200	6
Jasper.....	14	7	215	7
Soap rock.....	38	0	253	1
White quartzite....	2	0	255	1
Soap rock.....	11	6	266	7
Jasper.....	6	4	272	11
Soap rock.....	37	5	310	4
Chloritic schist.....	35	0	345	4
Soap rock.....	1	0	346	4
White quartzite....	4	0	350	4
Jasper.....	9	2	359	6
Chloritic schist....	36	2	395	8

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole O—[Drilled Aug. 11—Aug. 29th, 1888]; angle 38°; vertical distance 64.3 ft.

Marked [.....].

AT ARMSTRONG VEIN.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft.	in.
Soap rock.....	16 0	16	0
Jasper.....	41 5	57	5
Paint rock.....	10 0	67	5
Jasper.....	37 1	104	6

Hole P—[Drilled Aug. 15—Sept. 2d, 1888]; angle 9°; vertical distance 44.91 ft.

Marked [.. ..].

AT SOUTH LEE VEIN.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft.	in.
Soap rock.....	207 5	207	5
Jasper.....	1 0	208	5
Ore.....	2 1	210	6
Ore and jasper.....	50 9	261	3
Jasper.....	21 11	287	2

Hole GG—[Drilled May 15—June 1, 1889]; angle, 33°; vertical distance, 164 ft., 4 in.; direction of hole, north; in swamp between S. Lee and R. R.

AT SOUTH LEE, $\frac{1}{4}$ MILE EAST OF MINE.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft.	in.
Dioryte (Graywacke)	258 10	258	10
Paint rock.....	17 9	276	7
Dioryte graywacke..	13 6	290	1
Black rock and magnetic ore	11 9	301	10

Hole 3—[Drilled Oct. 10—Oct. 22, 1887]; angle 80°; vertical distance 124 feet, 2 inches; direction of hole, north.

AT TOWER MINE, WEST END NO. 1, 3D LEVEL, IN CENTER OF VEIN.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft.	in.
Clean ore.....	52 2	52	2
Jasper.....	9 0	61	2
Clean ore.....	2 0	63	2
Mixed ore.....	3 6	66	8
Clean ore.....	3 6	70	2
Ore and jasper.....	4 4	74	6
Clean ore.....	5 0	79	6
Jasper.....	2 0	81	6
Clean ore.....	3 0	84	6
Jasper.....	41 8	126	2

Hole HH—[Drilled May 31—June 29, 1889]; angle, 51°, 41 in.; vertical distance, 258 ft., 5 in. Started 300 feet west of CC and bored toward ore vein.

AT MONTANA PIT.

Kind of rock.	Thick- ness.	Depth.	
	ft. in.	ft.	in.
Quartz and soap rock	104 3	104	3
Quartz.....	1 10	106	1
Quartz and soap rock	12 2	118	3
Paint rock.....	4 0	122	3
Quartz and soap rock	7 9	129	3
Quartz.....	1 0	130	3
Quartz and soap rock	15 9	146	0
Paint rock.....	4 0	150	0
Chloritic schist.....	29 0	179	0
Soap rock and paint rock	10 0	189	0
Paint rock.....	2 2	191	2
Ore.....	3 0	194	2
Soap rock.....	13 1	207	3
Ore.....	8 6	215	9
Soap rock.....	31 4	247	1
Ore.....	1 0	248	1
Jasper.....	8 0	256	1
Soap rock.....	1 11	258	0
Paint rock.....	1 0	259	0
Ore.....	22 6	281	6
Paint rock.....	1 6	283	0
Soap rock.....	29 0	312	0
Paint rock.....	4 2	316	2
Soap rock.....	2 0	318	2
Jasper.....	11 2	329	4

DIAMOND DRILL SECTIONS AT SOUDAN.

Hole V—[Drilled Nov. 1st-Nov. 15th, 1888]; angle 40°; vertical distance 262.2 feet; direction of hole, south.

Marked [. . .]

AT SAME PLACE AS HOLE U.

Kind of rock.	Thick- ness		Depth.
	ft.	in.	
Soap rock.....	202	2	202 2
Paint rock.....	64	0	266 2
Soap rock.....	21	0	287 2
White quartzite, soap rock and jasper...	4	0	330 3
Soap rock.....	77	6	407 9

Hole W—[Drilled Nov. 19th-Dec 3d. 1888]; angle 53°; vertical distance 295.5 ft.; direction of hole, south. Started at same point as holes U & V.

Marked [. . .]

AT SOUTH LEE MINE.

Kind of rock.	Thick- ness		Depth.
	ft.	in.	
Gray quartzite.....	64	5	64 5
Soap rock.....	176	6	240 11
White quartzite and paint rock.....	8	0	248 11
Paint rock.....	41	6	290 5
Jasper	2	0	292 5
Paint rock.....	12	0	304 5
Jasper	2	0	306 5
Soap rock.....	64	0	370 5

Hole II—[Drilled June 6th—June 25, 1889]; vertical distance—direction of hole, north.

Kind of rock.	Thick- ness.		Depth.
	ft.	in.	
Dioryte graywacke..	234	4	234 4
Paint rock.....	5	6	239 10
Jasper.....	2	4	242 2
Dioryte graywacke..	46	0	288 2
Jasper & mag'tic ore	19	6	307 8
Dioryte.....	67	7	375 3

As the holes were completed they were severally marked by iron rails inserted a suitable depth in the ground near the opening of the holes, and through these rails were drilled holes to distinguish them, the drilled holes having different intervals separating them, according to the accompanying records.

(1.) *Macroscopic Characters.* Outwardly this greenstone varies from a massive diabase-looking rock to a fissile, green chlorite-schist the fibers of which are elongated in a direction parallel with the general strike of the formation, but varying, in close proximity to masses of jaspilite or of boulder masses of other rock, so as to wrap round them parallel to their outside surfaces. It is most frequent as a green schist. As a chlorite schist it is almost free from free quartz, but at places more remote from the iron deposits it varies to a siliceous rock, the silica being frequently in the form of fine pebbles or grains of jaspilite, and

occasionally of vitreous quartz, and at other places taking the form of a white "talcose" novaculyte (No. 1557), in which the silica is so fine that the individual grains cannot be discerned, making a glossy felsyte, or developing porphyroidally. Also in the mines this green schist is replaced by a white soapy flour-like substance which has been considered magnesia by the miners, but which according to analysis of Mr. Herbert A. Wilcox, is principally a hydrous silicate of alumina, the product of slow decomposition of the silicates of the surrounding rocks. This is found both at Tower and at Ely. This white kaolinic substance becomes gradually iron-stained, in some situations, and so completely charged with iron peroxide that it appears like a soft hematite ore. In this condition it pervades the mines and shares with the hematite itself in giving the prevailing red color to all the works. Following is the analysis of this white substance by Prof. J. A. Dodge.

White Kaolinic substance (Chem. ser. No. 211) *found in the Tower mines.*
Survey Number 1449.

ANALYSIS.

Silica, Si O ₂	62.05
Alumina, Al ₂ O ₃	27.55
Oxide of iron, Fe ₂ O ₃	1.30
Lime, Ca O.....	.38
Magnesia, Mg O.....	.77
Potassa, K ₂ O.....	4.26
Soda, Na ₂ O.....	.31
Phosphoric Oxide, P ₂ O ₅.....	.11
Water, H ₂ O.....(chemically combined)	5.30

100.03

This greenstone causes some of the prominent elevations. It is firm and massive in some of the hills eastward from Tower and at the falls of Kawasachong it is the rock over which the water runs, all the way from Garden lake to Fall lake, (Nos. 356, 998, 999). Still further east it becomes fresher in crystalline character, and rises into numerous hills that run in a nearly continuous range from the central part of town 63-10 to the south side of Ogishke Muncie lake where it apparently constitutes the Twin peaks in the northern part of town 64-6. Toward the east still further it is quite conspicuous as a hill range, and runs under the Animike and gabbro at the southwest end of Gunflint lake, giving altitude to the Animike-gabbro hills in that neighborhood. There is some reason, however, for supposing that this eastern range of greenstone hills is more likely to belong to that belt of the Vermilion which is seen on the west side of White Iron lake. This consists chiefly in its association with occasional mica-schists, and with magnetitic rather than hematitic ore, and of the otherwise

anomalous discontinuance of the Vermilion series which appears on the west side of White Iron lake, in the southwestern part of town 63-10.

In company with the jaspilyte the green schist has suffered a crumpling and squeezing, or has been stretched and molded to conform to the adjacent harder masses. At the Breitung opening and at the Tower opening, the finely jointed or basaltified structure, which the schist has been made to assume under this squeezing and stretching, is well shown. One photograph was made to illustrate this at the Tower opening, and it is reproduced on plate I.

Analysis of the green rock enclosing the Keewatin ore.

The chemical composition of the green schist, in its massive condition, was ascertained from a sample (538 B.(H.)) from Sec. 4, 63-9. The analysis was made by C. F. Sidener, viz: (17th report, page 126.)

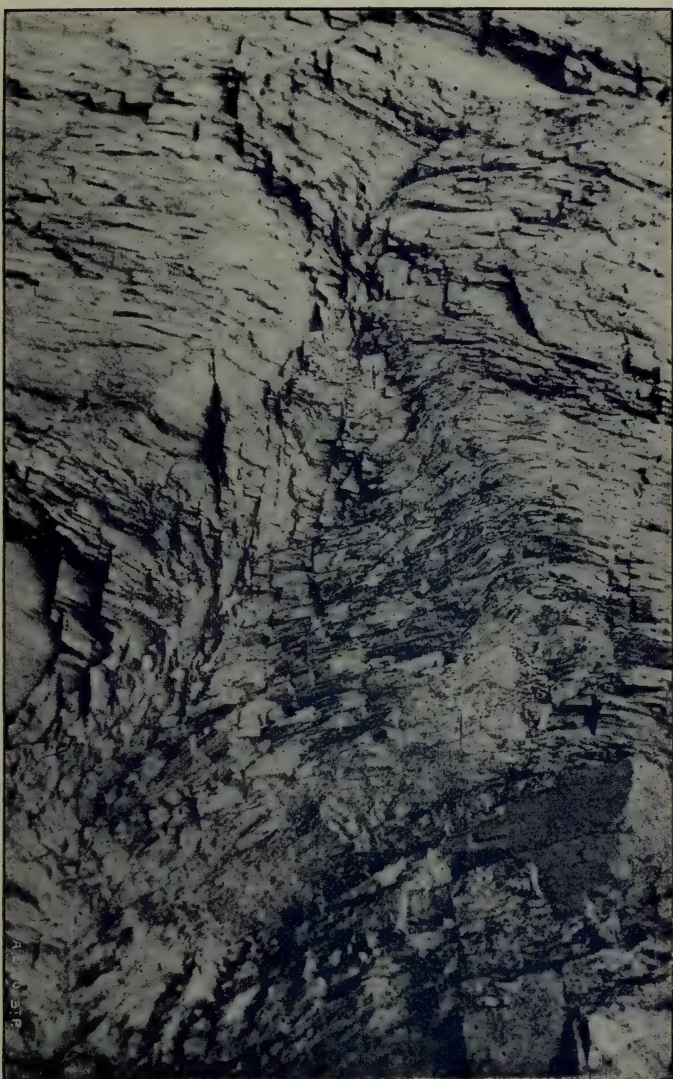
Silica, Si O ₂	50.47
Alumina, Al ₂ O ₃	18.45
Sesquioxide of iron, Fe ₂ O ₃	2.13
Protoxide of iron, Fe O.....	7.74
Lime, Ca O.....	6.61
Magnesia, Mg O.....	6.90
Potassa, K ₂ O.....	.30
Soda, Na ₂ O.....	2.58
Phosphoric acid, P ₂ O ₅	traces.
Water, H ₂ O.....	2.34
Total.....	97.52

The following shows the composition of this rock at the falls of the Kawishiwi, south of Fall lake. It is rock No. 356, sometimes called the "Kawasachong rock." Analysis by C. F. Sidener.

Silica, Si O ₂	43.96	per cent
Alumina, Al ₂ O ₃	16.03	"
Peroxide of iron, Fe ₂ O ₃	10.50	"
Protoxide of iron, Fe O.....	8.73	"
Lime, Ca O.....	9.54	"
Magnesia, Mg O.....	6.56	"
Potassa, K ₂ O.....	.27	"
Soda, Na ₂ O.....	1.62	"
Water, H ₂ O.....	1.84	"
Total.....	99.06	"

(2.) *Microscopic characters of the enclosing greenstone.*

The illustrations of the microscopic characters are on plate v, figs. 4, 5 and 6. The first published microscopic examinations of any of these greenstones was that of Prof. M. E. Wadsworth, as follows: "A dark-green, compact schistose rock. The section is composed of greatly altered debris, apparently of diabase, the fragments resembling a fine gray altered tufa (trachytic). The section is now largely altered to chlorite, micaceous scales, quartz



PINCHED AND CRUMPLED GREEN SCHIST. TOWER MINE. (P. 38.)

and magnetite, of which the chlorite predominates, with the quartz second in amount. Notwithstanding the great alteration of the section its fragmental structure yet remains complete." This description is applied to rock 356, from Kawasachong falls.*

The determinations of Dr. Hensoldt indicate a more massive, at least a more nearly crystalline, rock, having the characters often assigned to original eruptions. The rocks 999 and 998 have been specially examined. They are from the rapids at the Kawasachong falls, on the south shore of Fall lake.† The ordinary appearance of these in this section, magnified about twenty-four and thirty diameters, is shown in figures 4, 5 and 6, on plate v.

Hornblende Dioryte.

Rock 999.—[Plate v. fig. 4]—The principal constituents of this rock are plagioclase, hornblende and a greenish alteration-product, which may be termed viridite. If we examine a section under a magnification of, say, 60 diameters we observe a grayish feldspathic matrix or ground-mass, in which numerous crystals of hornblende of the usual dark-green color lie embedded. These crystals vary considerably in size; some exceed one mm. in actual diameter while others are barely distinguishable on account of their minuteness; their shape is mostly that of elongated scales or prisms, though rhombohedral outlines are by no means uncommon. These hornblende crystals have been rendered more or less turbid by decomposition and have become clouded by ferric hydroxide or dust-like magnetite, as alteration products, but in the main their characteristics are preserved.

In addition to the hornblende crystals large irregular colorless patches, surrounded by a pale greenish fringe, are noticeable in the feldspathic matrix, and in many instances these colorless masses present distinct hexagonal outlines. It is extremely probable that these are pseudomorphs after biotite, the latter having been completely changed into calcite and greenish fibrous epidote.‡

In the original condition of the rock the grayish matrix was doubtless a colorless triclinic feldspar (possibly labradorite) which has been rendered turbid by partial kaolinization. Its optical properties are now almost completely destroyed, no twin-lamellation and only a very faint chromatic display being noticeable. A few small colorless hexagonal sections indicate the presence of apatite.

*Bulletin No. 2, Minnesota Geological Survey, p. 123.

†Fifteenth Minnesota report, p. 319. The locality for 997 (p. 393) is wrongly given in the catalogue of rock samples. It was from the same place as 998, but nearer Fall lake.

‡All the smaller biotite scales have been transformed into chlorite or epidote, without a trace of calcite.

Dust-like grains of magnetite are scattered all over the field and a number of larger crystals with distinct cubical and octahedral outlines are likewise observable.

Rock 998. A hornblende-dioryte of similar structure and composition as 999, but containing a perceptible admixture of quartz. The hornblende scales are much larger than in 999 but their feeble dichroism indicates a more advanced chloritization. The feldspar is exceedingly turbid and has lost its optical properties, no twin-lamination being perceptible in any of the crystals, but the forms of the original prisms are still preserved. The quartz-grains have a fragmental appearance and do but seldom show rounded forms; they are small and easily distinguished by their transparency and brilliant polarization. This dioryte contains little if any magnetite, but we observe in the section numerous crystals of titaniferous iron, surrounded by a peculiar grayish-white alteration product. This is evidently the same rock which has been briefly described by Dr. M. E. Wadsworth, under 356, in Bulletin No 2. of the state survey (p. 123). The writer has carefully compared the different sections (viz. 998 and 356) and has found in both the same minerals, in precisely the same form and stage of alteration. Dr. Wadsworth, however, has failed to identify the titaniferous iron, mistaking it for magnetite. The latter invariably changes into rusty limonite and never forms a grayish decomposition product, which is a characteristic of titaniferous iron.

It has already been stated that some parts of the Keewatin schists have been subjected to pressure, folding and apparently nearly to fusion. At any rate they have been made to assume the different shapes and outward structures that are commonly ascribed to primary eruptives. Such appearances have been described at several places in the annual reports of the Survey. Plate I represents a jointage that resembles that assumed by basaltic rocks on cooling, seen in the green Keewatin schists where they have been exposed at Tower in the operation of the mines. This schist on the weathered surface is seen to crowd into all the accessible sinuosities of the jaspilite, and to conform in all respects to its exterior shapes. In other places about Stuntz bay (15th report pp. 314-317), the Keewatin sediments have been made to act the role of eruptive rock. They become massive, acquire a basaltic structure, and crowd over and cut across the schistose structure of the adjoining strata. The rock having this igneous manner seems sometimes to be involved, in the vicinity of Stuntz island, and on the mainland further west, in the agglomerate which there prevails, somewhat like a dyke, but really wedges out in a

lenticular manner. Its contact with the agglomerate shows nothing noteworthy. There is nothing indicating any effect it had on the agglomerate, which shows the two rocks had nearly or quite the same temperature. There is simply an abrupt transition from a schistose coarse rock with boulders to one without boulders, of the same color, massive, or coarsely jointed in a basaltiform manner, and homogeneous in mineral characters. In other places the green schist seems to graduate into this eruptive-acting rock, and becomes there associated unconformably with graywacke and argillite. A patch 30 feet across strikes diagonally across graywacke. It has a perfect basaltic columnar structure, and contains semi-rounded quartz grains distributed somewhat like quartz in a porphyry, though not of uniform size. It appears as if it could have been produced by the more or less complete local fusion of the materials of the surrounding rock (compare rock No. 1, H).

The rock which is described below and designated an "altered minette or syenitic lamprophyre" (No. 868 A) was obtained on the southern slope of the "south ridge," near its western end, and its relations to the adjoining rocks are described on page 267, of the fifteenth annual report. It is of the same class and origin as those already mentioned above. It graduates into the green schist of the region, and the green schist into argillite. It is mainly massive, but acquires, at exposed places, a schistose structure coincident with the direction of the green schist. Feldspar crystals are developed in it in differing stages of distinctness. It also retains traces of its original fragmental structure in the forms of boulders that appear scantily scattered over its weathered surface.

Further stages of change in the sediments of the Keewatin have been noted about Kekekabic lake, where the feldspar is more perfectly formed in idiomorphic crystals, making a porphyritic rock, which, rising massively and firmly above the surrounding surfaces, shows on its weathered surface numerous included boulder-forms of different sizes and composition. Compare Nos. 1094, 1402, and others from Kekekabic lake, 16th report, pp. 100-105.

It appears that by some force the Keewatin beds were greatly compressed and folded. This pressure was accompanied by heat and moisture. The elements which were at first disintegrated to form the sediments were so far fused by this action that they were enabled to reunite, according to their chemical affinities, producing, on cooling again, those crystalline minerals which before went to make up the sediments. In many cases the crystallization was not completed, but the process was interrupted, such interruption causing, apparently, the dimness of outline which sometimes these

re-formed crystals manifest, their shapes and their color and composition not being sharply separable from the matrix in which they began to grow.

Rock 868 A.—(Plate v, fig. 6).—This is an altered minette or "syenitic lamprophyre" (of Rosenbusch), which occurs in various structural modifications. It is a compact, semi-crystalline rock with an approach to porphyritic development (as in most of the older intrusive vein-rocks) but assuming in some places an almost schistose character. The prevailing color is a light greenish-gray, passing here and there into various shades of red and brown.

If we examine a section prepared from the typical greenish variety (868 A) we observe a turbid feldspathic matrix, finely granular or aphanitic, in which large porphyritic crystals of kaolinized orthoclase are embedded. The latter are, practically, pseudomorphs, as they are identical in substance with the ground-mass, from which they can only be distinguished by their outlines and their inferior translucency. Most of these orthoclase pseudomorphs are idiomorphic, viz., bounded by their own crystal planes, which denotes solidification from an originally molten state.* Their optical properties are almost completely destroyed, yet in a few instances faint traces of the peculiar cross-hatching or pectination of monoclinic feldspar are noticeable between crossed Nicols. In addition to the orthoclase pseudomorphs we observe dark-green chlorite, in the form of elongated scales and irregular patches, distributed throughout the field. Examined with a half-inch objective these patches are found to possess a semi-fibrous or granular structure and to be associated with small grains of magnetite which are partly converted into yellowish and brownish limonite, causing a rusty stain. Whether this chlorite has resulted from the decomposition of an original biotite or hornblende must remain an unsettled point till a section can be secured which shows either the one or the other mineral in its actual state of transition. It is possible that both biotite and hornblende were original constituents of this rock, as in most of the minettes which have come under the writer's observation.

Rock 868.—This rock differs macroscopically from the one previously described (868-A) in having an almost schistose structure; microscopically the resemblance is very close. We observe the same aphanitic matrix, enclosing porphyritic orthoclase crystals and

*Orthoclase, requiring an enormous fusion-temperature, would be the first to solidify in a cooling magma, thus its crystals could not possibly be modified externally by the crystals of any of the subsequently solidifying minerals. They may, however, be fractured or broken.

greenish masses of chlorite, partly stained and discolored by rusty limonite. The orthoclase individuals are, however, in a more advanced stage of decomposition and have been so completely metamorphosed that even their outlines have become indistinct, and, in many instances, quite lost. In No. 868 A we could still notice faint polarization colors in the kaolinized crystals, but in the present rock we have a total absence of chromatic phenomena.

There can be little doubt that 868 represents an older type of the same intrusive rock, as evinced by the more complete decomposition of its principal constituent, as well as its schistose structure. If we were confronted by the latter circumstance alone we might hesitate to argue from it in discussing the problem of relative antiquity, but the condition of the orthoclase crystals clearly points in the same direction. The process of kaolinization in orthoclase, not exposed to surface weathering, is an exceedingly slow and gradual one, and perhaps no other rock-forming mineral affords a safer guide in determining the chronological order of metamorphism in the ancient crystalline and panidiomorphic rocks. The question here involved is one of cardinal importance. Are all the types referred to in the state geologist's fifteenth annual report (pp. 264-268) viz. Nos. 868, 868 A, 868 B, 868 C, 868 D, 868 E and 868 F, modifications of one and the same rock? If so, did the parent-rock present these structural differences already at the time of its formation or were they effected by local changes in an originally homogeneous mass? Furthermore, did the changes (if subsequent and local) occur contemporaneously and gradually, or are they due to sudden complications after intervals more or less considerable? That any rock should, within the limited area presented by 868-868 F, be so differently affected by contemporaneous agencies (whether sudden or gradual) seems utterly inconceivable; it would imply a bewildering complexity of conditions. Why, if one part of the parent rock was altered, by conditions which must have prevailed for ages, were the others not similarly affected? Why should a well-characterized minette—one of Rosenbusch's intrusive vein-rocks—pass into a coarse conglomerate on the one hand and into a fine slate on the other? If we are really here dealing with contemporaneously formed rocks it would be absurd to attribute to these rocks a sedimentary origin. Besides, it may be asked, did sedimentary rocks, in the commonly accepted sense of the term, really exist at that remote period? The writer is inclined to doubt this. Sedimentary rocks, formed of the material of previous plutonic or metamorphic masses, imply the existence of islands or continents of which they are the detritus, and it is exceedingly improb-

able that extensive land-areas should have risen above the ocean-level at so early a stage of our planet's history.

Rock 1557.—This is a whitish-gray quartziferous talc-schist, composed of a fibro-granular, almost aphanitic, matrix, in which numerous angular quartz grains are imbedded. The latter are quite pellucid and their brilliant polarization-colors form a marked contrast with the isotropic matrix. It would seem, however, as if quartz or amorphous silica was also present in the matrix, not in the shape of distinct granules, but in a finely divided, almost jaspilitic condition. The talc is either an alteration-product of augite, hornblende or enstatite. Compare the 18th annual report, p. 42. This rock was obtained at the roadside, where it is crossed by the railroad, near the Tower mine, on the south slope of the "North ridge," and represents a not infrequent condition of the finer part of the Keewatin sediments.

Rock 869.—A soft, greenish-gray, chlorite-schist, with an almost slaty cleavage. It is composed of closely matted scales of chlorite and talc, but the structure is so minute that a magnification of from 300 to 700 diameters is required for its examination. In sections cut parallel to the plane of cleavage the chlorite-scales appear pale green and we notice that their boundaries are so indistinct that in most instances it would be difficult to ascertain the prevailing forms. Many of the chlorite-scales contain needle-like crystals of rutile, derived probably from previously existing titaniferous iron. The latter exhibit the yellowish translucency peculiar to rutile, if examined with an "eight-inch" objective. The talc-scales are perfectly colorless, well defined in outline and free from enclosures. They do not show the faintest pleochroism, but polarize in feeble tints of blue and gray. In this latter respect they differ from the chlorite, which is totally isotropic. There are grounds for believing that this rock was originally an amphibolyte consisting almost exclusively of hornblende (with a smaller admixture of titaniferous iron). The hornblende was changed into chlorite which is now being converted into talc, the metamorphosis being about half completed. Such a rock would be ultimately transformed into a regular talc-schist. This rock was obtained at the west end of the "south ridge."

Rock 919.—A chlorite-schist, almost identical in structure and composition with that described under 369. It shows the same close interfoliation of talc and chlorite, but the chlorite is better developed than in 869 and predominates over the talc. This rock is quartz-bearing (a feature which we did not observe in 869) but the quartz does not occur as a constituent of the chloritic strata,

but forms thin sheets or layers interposed between the latter. This is from the railroad cut south of the Stone mine.

Rock 864.—A dark, heavy chialstolite-slate, resembling the so-called "knotenschiefer" of German petrographers, as it presents numerous small lenticular concretions along its cleavage (which is somewhat irregular and fissile). Its principal components are chialstolite, talc, chlorite and an opaque "carbonaceous" substance, which is probably finely divided magnetite. The chialstolite crystals have mostly rhombohedral outlines, but are otherwise almost in the condition of pseudomorphs as they have lost their transparency and appear to be partly converted into a semi-fibrous or granular decomposition product. It is to these chialstolite crystals that the peculiar "knotty" structure of the rock is due, as they form the substance of the lenticular concretions. The hardness of the latter almost equals that of quartz. The talc-scales are comparatively large, and even more pellucid than in 869, showing the same absence of pleochroism, but polarizing in more lively colors. Chlorite is now only a minor accessory (having in the writer's opinion been mostly converted into talc); its color is a muddy green but no distinct forms are anywhere recognizable. This is a rare rock in the Keewatin. It is from the south shore of Jones bay.

The agglomerates (sometimes properly called conglomerates) which abound in the Keewatin are of problematic origin. Some of them, particularly those which embrace numerous masses of rock, large and small, which are greenstones and resemble closely the rock in which they are embraced, are found to constitute a large part of the more massive portions of the formation, and may be supposed to be referable to submarine volcanoes which ejected not only great quantities of tuff and volcanic bombs which fell at once into the surrounding ocean and were by it transported to more distant parts, but also vast outflows of basic lava. All these products were subjected to the violent chemical action of the heated atmospheric waters or to the alkaline oceanic waters into which they fell. Such periods of agitation were favorable for the rupturing of the prior formed beds, whether of siliceous or basic composition, and whether the result of chemical precipitation from oceanic water or of mechanical transportation and deposition, and for the mingling of such materials with the accumulating volcanic products. The rounded stone which is represented by 2 B (H) is but one of thousands that could be extracted from the conglomerates of Ely and Stuntz islands. The enclosing rock is in the main a silky schist varying by reason of its finely siliceous texture

and composition to a rock like 1557 (described above), and to a more siliceous and firm felsyte, like that seen in this pebble. Wherever the pebbles of these conglomerates consist of non-basic materials they seem to have been of mechanical origin and derived from older strata existing near. One of the most frequent, and yet one of the most perplexing facts, in connection with these conglomerates, whether of acid or of basic pebbles, is the identity of the lithology of the pebbles with the strata in which they are embraced. That the rock that furnished the pebbles themselves was of fragmental origin originally, is indicated, as stated below, by the presence of fragmental grains of quartz. In this case, however, and in nearly all others where these siliceous pebbles have been examined, there is evidence of the precipitation of much of the silica from solution, this process going on simultaneously with the fragmental accumulation. We have thus three stages of accumulation proved by these boulders—1st, that of the smallest fragmental grains; 2nd, that of the boulders; 3d, that of the strata that contain the boulders—and in all of them the physical and chemical conditions were so similar that there can be discovered no essential difference in the rocks which were produced. This is analogous to the shattering *in situ* of the last formed layer of jaspilyte (fig. 8), by some force which was not able to remove the fragments, but which allowed the immediate resumption of the process of accumulation (in this case chemical precipitation) which preceded, and which, indeed, formed the shattered layer itself; but it is more nearly identical with that process which both shattered and removed the jaspilyte beds from their places and scattered the pieces among later formed jaspilyte.

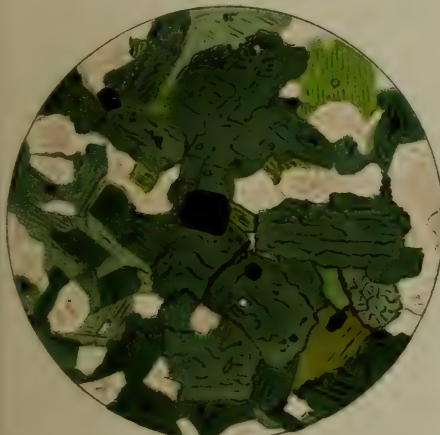
Rock 2. B. (H.)—[See the fifteenth report, p. 304.]—This remarkable rock occurs in the shape of rounded masses or boulders in the schist of Ely island, and may be termed a porphyritic felsyte. It is composed of a micro-felsitic basis, which, even under high powers of magnification, is not separable into true individualized parts but consists of indistinct granules and fibres, which transmit a feeble, fluctuating light. Embedded in this matrix are crystals of whitish orthoclase and a few rounded quartz-grains. The orthoclase crystals are so turbid that it is easier to recognize them with the naked eye than under the microscope, where they can only be distinguished by their outlines. They appear to have been completely kaolinized and subsequently indurated by silica, deposited between the disintegrated particles. In reference to the rounded quartz-grains we can see at a glance that they are water-worn pebbles. They vary in diameter from

FIG. 1.



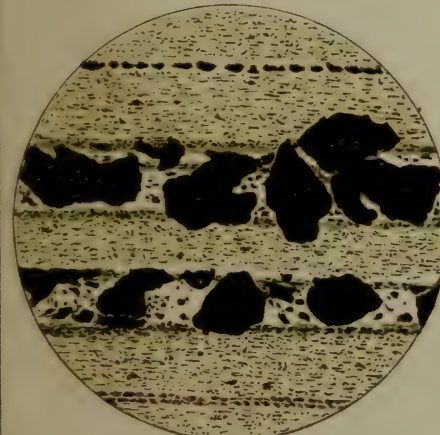
407 B × 24

FIG. 2.



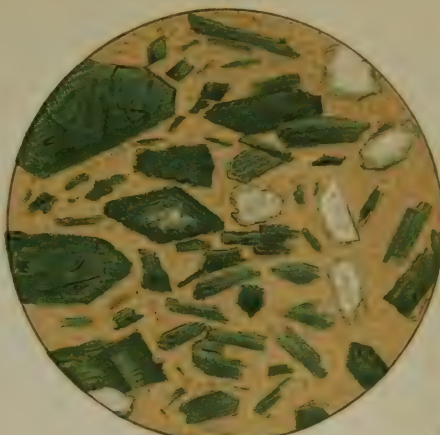
416 (H) × 30

FIG. 3.



1446 × 24

FIG. 4.



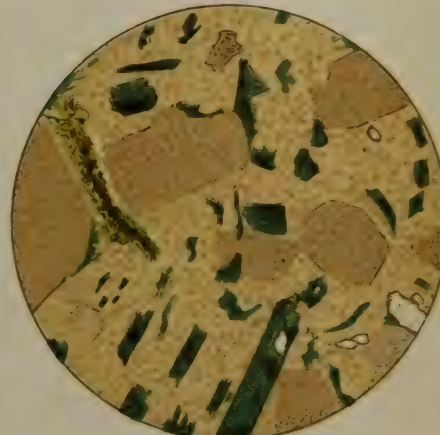
399 × 24

FIG. 5.



416 × 30

FIG. 6.



655 A × 24

that of a pin's head to that of a large pea, and contain numerous fluid-enclosures, arranged in lines, exactly as in rock-crystal and in the quartz of granites. There cannot be the shadow of a doubt that these quartz-grains existed previous to the formation of the rock in which they are embedded and that they are older than the other constituents. The mere fact of their presence suffices to demonstrate the sedimentary origin of this rock, or at least to exclude the hypothesis of a possible igneous derivation. These grains must have been introduced during the process of the formation of the rock, which probably was once in the condition of a soft sediment; the interstitial silica may have been chemically precipitated but the orthoclase may be a product of intra-molecular or crystallo-genetic activity.

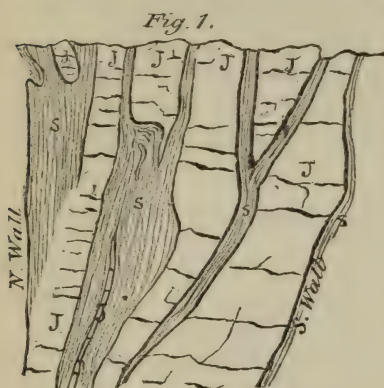
(b.) *Structure and character of the hematites of the Keewatin.*

(1.)—*Structural features of the ore.*—Here will be mentioned only the physical aspects of the ore-bodies. In general the ore lies in lenticular bodies elongated northeast and southwest in parallelism with the schists. These vary in size from mere pebbles to belts that can be traced sometimes over a mile continuously. When the bodies are small they are apt to be so poor in iron that they are not mined. Indeed it is true that most of the jaspilyte is too siliceous to be valuable as ore, the silica being simply stained by iron in such proportions as to make reddish and pinkish shades. The large bodies that are worked at Tower have such lean spots that they are rejected, and also such highly siliceous spots that they are not even mined. Probably three-fourths of the whole jaspilyte mass, as it occurs in the ridges at Tower, is worthless as iron ore.

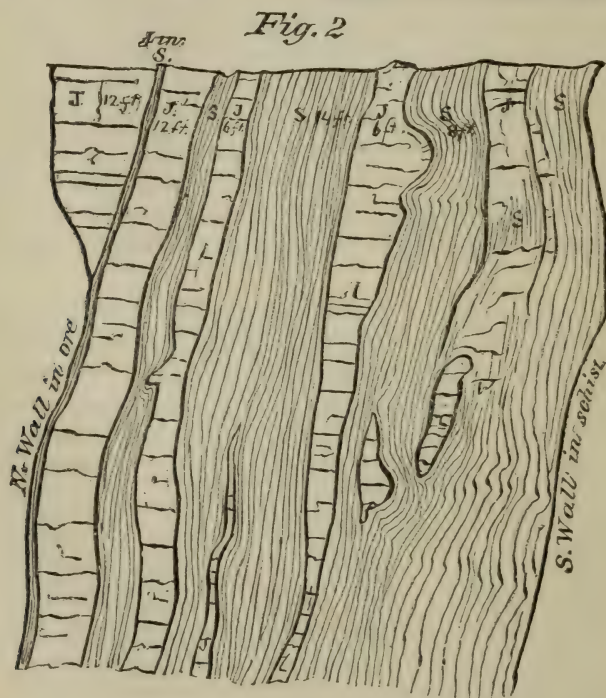
This siliceous, ribboned jasper is made up of all possible variations between pure silica and pure hematite, the different colors being due to the different relative proportions. Its parti-colored glaciated surfaces are very beautiful. Its serpentine windings are plainly exhibited. (See fig. 22, p. 257, 15th Rep. and fig. 5, 17th Rep.). Being the firmest portion of the hills it forms their tops after the destructive erosion of the glacial epoch, and frequently for long distances it can be walked over without any obstruction or interruption other than a fallen tree or a mass of drift boulders. The silica and hematite bands run parallel to themselves, but are bent, re-torse, incurved, again revolute, abruptly broken and re cemented; faulted minutely, any separate band independently faulted, or the entire mass suddenly jogged to the north or south.

The relations which these siliceous bodies sustain, stratigraphi-

cally, to the enclosing rock are interesting. Generally they are entirely and abruptly distinct from the greenstone, or green schist that encloses them. Occasionally they are cut across, or interbanded, nearly parallel with their own direction, by bands from six inches to ten feet in thickness, of the green schist. In these cases* there is no intermixture of the schist with the jaspilyte. The figures below (figs. 1 and 2) represent the alterna-



tions that may sometimes be seen at Tower between the green schist and the jaspilyte. In some cases such alternating beds of jaspilyte are good ore and in others they are too siliceous. These figures were sketched at Tower, one from the east wall at opening No. 5 and the other from the east wall of opening No. 6, known formerly as the East Ely and West Ely mines. Each one of these beds of jasp-



*Compare the 15th report pp. 225-226.

lyte has a fine lamination which is much contorted. The schists which are pervaded by a schistose structure, when not reddened by iron, and which when reddened are less schistose and "baked," though soft, do not manifest, so distinctly, a finer internal lamination. The four-inch bed of schist, at the left of figure No. 2, runs the whole length of the mine, and even appears on the stripped surface east of the opened pit, traceable 500 or 600 feet altogether. At the next opening further east, a similar alternation of beds of schist and beds of ore can be seen, the schist beds being three in number and from six to ten feet thick, the whole width across the ore mass being from 75 to 100 feet.

While these jasper lenticules are generally free from the green schist, yet they graduate downward in size, and pass to mere pebbles and grains no larger than a pin-head. In this finely disseminated state they are mixed with the schist, and arranged in other places in sedimentary strata. When they are coarser, and yet not in their native places, they cause a conglomeritic composition in the green schist, and in these finer conglomerates they help to constitute the graywackes of the formation. At points

somewhat remote from the main ore masses the jaspilyte rapidly degenerates as to its content of hematite, and becomes simply chalcadonic quartz. At the same time it is mingled with grains of distinctly vitreous, crystalline silica which seem to have a different source. Figures 3, 4 and 5 illustrate the manner in which some of the jaspilyte masses are disseminated through the

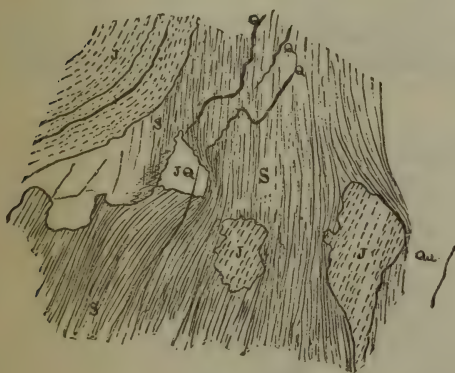


Fig. 3.

schists*. In these fragments the jaspilyte shows its original bedding, and angular outlines indicating that it was not far transported from the place of its origin, and was soon buried under accumulating schists after it was broken up and distributed.

Explanation of Figure 3.

S. Schist, its fibrous and wavy structure bending around the jaspilyte inclusions.

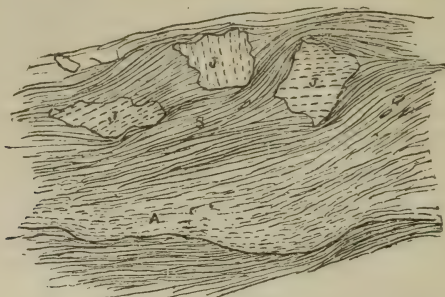
J. Jaspilyte in angular fragments, showing nonconformable earlier fine laminations.

*From A. Winchell's report, 1886, Fifteenth Report, Minnesota Survey.

QQ. Quartz veins, vitreous and distinct from the quartz of the jaspilyte.

Qu. Quartz. JQ. Jasperry quartz.

The figure was sketched from nature, NE. part S. W. $\frac{1}{4}$, SE. $\frac{1}{4}$, Sec. 20, 62-15, south shore of Vermilion lake.



Explanation of Figure 4.

This figure represents the structure of schist at the same point as figure 3.

S. Schist, with bending structure accommodating itself to the jaspilyte pieces.

J. Jaspilyte, evidently introduced while the layers of schist were forming, broken from some pre-existing formation when they had already received their banded structure.

A. Here there may be seen a local graduation of the schist into quartz, 'showing that some quartz was accumulating contemporaneously with the schist.'



Explanation of Figure 5.

This was sketched about 20 rods northeast from figures 3 and 4.

J. Jaspilyte, with broken outlines, forming a coarse breccia.

S. Schist.

In all these cases it will be noted that the jaspilyte, which is the rock which embraces or accompanies the ore bodies whether valuable as ore or not, and whether large or small, and whether in its native place or transported and embraced as foreign bodies in the green schist, is a foreign substance brought from its native place by some unknown force and deposited in the finer sediments of the schist while they were being accumulated. These are unlike the coarse, bedded, long-extended alternations seen in figures 1 and 2, which show that the jaspilyte masses are in their native places, and that the force that formed them alternated with the force that formed the schist. It is apparent, again, that the larger bodies which lie now *in situ* among the schists, were the parent sources for the fragments that, at other points, are scattered through the schists, and that some force, or succession of forces, was active, which was capable of breaking up the masses *in situ*, and of distributing them at once among the still forming sediments of the same age. This disruption of the jaspilyte bodies involves the previously formed strata of the schist, as will be evident by the following figure (fig. 6) where in the same brecciated mass can be seen jaspilyte and green schist. It is but rarely that breccias consisting almost entirely of the schist in angular pieces are found, but such occur near the Breitung mine (opening No. 13) and such are represented by rock sample No. 1,563.



Fig. 6.—Breccia containing green schist and jaspilyte pieces.

Explanation of Figure 6.

Sketched from a fragment in the dump at opening No. 1.

1. White chalcedonic silica, thinly and sparsely banded with hematite.
2. Conglomerate and breccia of green schist and brown jaspilyte. The

black part represents green schist. Some of the separate pieces are sub-rounded, others are elongated and sheeted.

3. White silica and hematite, beautifully banded.

The breccia of green schist and brown jaspilyte (No. 2 of fig. 6) was accumulated during a general period of accumulation of jaspilyte, indicating some rupturing agent that affected both rocks. Indeed there are many evidences that there was a force, whatever it was, that was capable of fracturing the last laid down thin layer, without affecting the others, also that some force was active in rupturing and transporting in a common manner both the acid jaspilyte and the basic schist. At many places fragments of the jaspilyte may be observed scattered unconformably in the schists, and at other places a breccia of schist and jaspilyte may be seen, particularly in the opening southwest from the old Breitung mine, but it is rare to observe unconformable pieces of the green schist embraced in the jaspilyte. This rarity of the green schist in this situation may have been due to the greater ease with which it was disintegrated and lost in the general sedimentation.

Thus far the most marked and evident relations of the schist and jaspilyte have been mentioned. It has been stated that they were accumulated under the operation of an interrupted force, or a force acting on different objects uniformly, one result being suspended while the other was transpiring. That is the most evident and most frequent condition. The planes separating the great jasper lodes from the country rock are distinct, the transition is abrupt and complete in the narrowest possible space, the separated surfaces being very often slickensided, showing some movements in one mass in which the other mass did not participate.

We have now to observe that occasionally there is a sedimentary alternation more minute, and that the distribution of the materials of the jaspilyte was cotemporaneous with that of the green schist, and was due to the same agent,* whatever may have been their sources. This fact it required long search to establish. The first observation of this intermingling in definite strata formed by sedimentation was made at the railroad cut south of the old Ely mines (now openings No. 5 and 6) at the Minnesota mine, and it is illustrated by rock No. 894. This interbedding of schist and jaspilyte, the latter being somewhat purple, extends along the railroad as far east as to the old Stone mine (now openings Nos. 2 and 3) where it is again well-exposed (see rock samples 914). Here the jaspilyte passes by gradations into the green schist by mingling of the minute granular parts, the resulting rock being neither schist

*Compare the fifteenth annual report pp. 221, 224.

nor jaspilyte. In the immediate vicinity are jasper nodules, indigenous in the midst of the schist, red and purple, some of them five or ten feet long, appearing like quartzose aggregations in the midst of their native sediments, but at a little further south being white instead of purple. Subsequently a similar minute succession of beds of alternating jaspilyte and green schist was observed further west, on the southern slope of the "south ridge." Here are some interesting exhibitions of the relation of jaspilyte to the schist, some of them showing the minutest interstratification of the

jaspilyte with the sericitic sedimentary schists, and others exhibiting the manner in which isolated, transported masses of the jaspilyte are surrounded unconformably by a chlorite schist. Of the former the following sketch was made (figure 7):

The area here represented can be seen to extend with the strike a distance of twelve feet, when the characters fade out gradually by the loss of the siliceous element, the rock becoming entirely schist. Before this takes place the siliceous bands are interrupted, and some nodules and accretions appear in place of the continuous sheets of silica.

The quartzite (or jaspilyte) on the weathered surface is light gray, but on the freshly broken edges shows the jaspilitic colors. The schist is fine and evenly laminated, in its alternations with the quartzite, and with itself, not being disturbed by coarse sediments, or by faults or contortions. This is one of the most perfect illustrations that has been seen of the manner of transition from the jaspilyte to the schists. Indeed there is here no general transition,

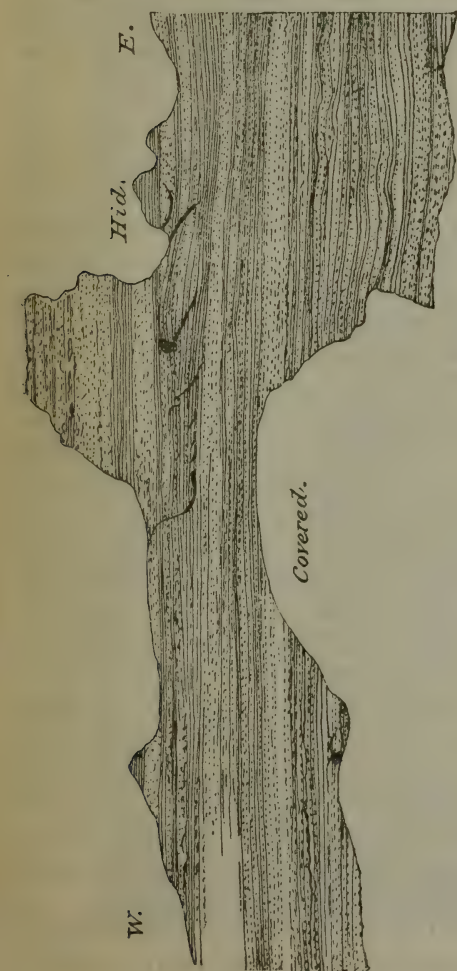


Fig. 7.

since nothing but green schists exist on either side of it for a distance of eight or ten feet, as far as the rock is exposed. The diagram shows rather

that the jaspilyte is in thin interstratified sheets within the sericitic schists. The sketch does not show, and cannot be made to, all the fine interlamination and gradations between the two, since the schists themselves become arenaceous and gradually lose their green tint, becoming gray, then white, then purple, when broken, and requiring the designation jaspilyte. The thickest distinct lamina seen here is about one inch, and the thinnest is a mere film and becomes lost in the schist. This is a true interstratification due to sedimentation, visible both in the jaspilyte and in the schist. The strike is ten degrees south of west, and the bedding is vertical, or dips at an angle of 89° toward the north. No drawing can do justice to the minute mingling of silica bands with schist bands. The continuous lines indicate silica sheets, and the broken lines indicate the schist. The black irregular patches are intended to show chemically deposited vitreous silica. The distance across the bedding is three and one-half feet, and is exaggerated in respect to the length actually included in the sketch.

Another observation of a mingling of the sericitic element with the siliceous was made in the summer of 1889, indicating still different circumstances. In the last case it will be noticed that there is an interlamination of the two in distinct, thin laminae, and that the prevailing element is the green schist, but in this case it was observed on a general glaciated jaspilyte surface, where the prevailing element was quartz, that green schist layers, contorted in much the same manner as the associated sheets of colored jaspilyte, were introduced. This was seen on the northward slope of the "north ridge", north from the Tower mine (now known as openings 7, 8 and 9). Here in the midst of the general jasper contortions (see plate II.) is a belt which is markedly different from the rest, being greenish, and was at once taken for a schist bed. It was carefully sketched, with its associated jaspilyte bands, but on close inspection it was found to be composed not entirely of the element of the green schist, but had a liberal percent of the fine silica, indeed was so siliceous that were it not for the contrast it presents with the smooth, hard jaspilyte on either side it would hardly be considered green schist. It fades generally, in other beds, into a softer (yet siliceous) light-green schist which cannot be mistaken for anything else. It appears hence that in the same greenish schist, embraced within this jaspilyte mass, which elsewhere embraces the jaspilyte masses, there is a minute indiscriminate mixture of the elements which generally appear as contrasted constituents of the rocks of the country. It appears further that the schist layers were formed before the contortion, and participated in it, and were not differently introduced so as to be independent of it. This green schist here contorted with the jaspilyte is represented by rock No. 1571,



CONTORTED JASPILYTE, ON THE N. SLOPE OF THE NORTH RIDGE, NEAR THE TOWER MINE.
(THE HAMMERS LIE ON THE LAMINÆ OF SILICEOUS GREEN SCHIST.) (p. 54)

(see thin section, plate IX). This jaspilyte surface is illustrated by plate II.

Explanation of Plate II.

Crumpled jaspilyte surface on the north slope of the *North Ridge*, near the Tower mine or openings numbered 7, 8 and 9. At the left of the plate the hammer-heads lie in two belts, or laminæ of green schist, as described in the text, crumpled with the jaspilyte and hematite. Being weathered out more rapidly they have caused crooked furrows which reveal their nature and their relation to the jaspilyte on either side. The broken hematite band which is illustrated in figure 8 occurred in the midst of this jaspilyte surface at the right of this plate.

On the north side of Otter Track lake are similar transitions between the materials of the jaspilyte and of the schist. They were described in the seventeenth annual report (p. 114). They are on a much larger scale. Sometimes the rock itself seems to fade into jasper, and to become ferruginous and banded. At other times the rock is quite massive in appearance and has an abrupt contact with the enclosed masses of jaspilyte. This also illustrates the fact that in the midst of the forming Keewatin schists, there were gentle forces that operated to mix the iron-jasper elements minutely, and that contemporaneously there were violent forces that tore up and shattered the beds lately formed and mixed the angular fragments with the next formed schists.

Still another observation was made near Tower, on the south slope of the "south ridge", by which a very different mingling of these rocks was revealed. Here the two are not inter-laminated, nor intimately blended as in the last, constituting a rock intermediate in character between the schists and the jaspilyte, nor yet mingled in the form of a breccia. That is, they have not the aspect of a breccia. The surface of the rock at this place was photographed in 1886 (see fifteenth report, p. 229, foot note), and the photograph is reproduced by half-tone electrotype in plate III.

Explanation of Plate III.

This plate illustrates the surface of the rock (nearly horizontal) at a point about fifteen rods east of the place illustrated by figure 7. The siliceous parts are not in the form of parallel bands running in the direction of a sedimentary structure and forming a part of it, such as seen in figure 7, but the silica is in fine lumps, drawn out in the direction of the schistosity, some of the lumps being not more than a sixteenth of an inch in thickness, or a mere film, and some of them being an inch or two. There is in some places (not shown on the plate) a fine threadlike interlaced mesh of roughness caused by the more enduring silica ingredient standing up on the surface of the weathered schists. In the interstices of the mesh is the schist, some of the areas of the softer rock being inclosed, or nearly inclosed, by the harder, but for the most prevailing over the harder in one direction, and giving place to more and more of the siliceous ingredient in the other. There is visible here

no true sedimentary banding, but the jasperoid silica is disseminated irregularly through the schist. There is no graduation of the schist into the silica by varying amounts of fine silica in a soft green or grayish mud; but the silica, even in the smallest lumps, is pure silica, and the schist does not perceptibly vary in its characters. In one direction, as the silica increases, it forms larger and larger lumps, so that some of them have the characters of jaspilyte, but without the parti-colored banding. Instead of banding the colors are in blotches. This is seen at the right of the plate in several lenticular masses of jaspilyte. Still further in the same direction, as the jaspilyte masses increase in size, so as to constitute the most of the rock, they are somewhat banded by alternating colors, and sometimes the banding is transverse to the schistose structure.

It would seem, from the facts mentioned in the description of plate III, that this lumpy silica is due to the dissemination through the green schist, of small pebbles and larger masses of jaspilyte which had before been formed as jaspilyte and had received its banding, while the schist was being accumulated rapidly. Originally they may have been angular or rounded. It is evident that their shapes now are accommodated to the dominant direction of the schistosity, and they are so intimately inter-locked with the schist that they appear to have been contemporaneously formed where they now lie as constituent results of the schist-forming force. But these grains and masses are foreign to the schist. They do not mingle with it, though so intimately mixed with it. It is possible that at other points, in the vicinity further to the left, or even at a time cotemporary with the formation of this, these pieces of jaspilyte were reduced by sedimentary selection so fine that they are comparable with the minutest siliceous grains of the jaspilyte, and in that case might produce the sedimentary structure seen in figure 7, but no such transition has been observed. We are left to infer, therefore, that this plate represents a breccia, or a conglomerate, which may have been like those represented by figures 3 and 4, or some modification of them, and that by pressure and shearing the entire granular arrangement has been changed, every piece having been stretched into greater dimension in a direction parallel with the schistose structure. While this elongation is stamped on the larger masses (not shown in the plate) their original shapes have been better preserved, and their internal structure is still evident. It is the smaller pebbles that are most distorted by this shearing.

Other physical peculiarities might be mentioned. One of the most important is the separation of some of the layers from a general jaspilyte mass in an oblique direction and their running transversely to the schists in a manner somewhat resembling a dike of trap rock. Such appearances are not common. Indeed, but one or



VIEW NORTH OF TOWER. TO SHOW THE GRADUAL INTERSTRATIFICATION OF THE
JASPILYTE AND SCHIST. (P. 56.)



SO-CALLED TRIBUTARY DIKE OF HEMATITE, STONE MINE (NO 10), TOWER. (P.57)

two are known at Tower. They seem to be more common at Marquette. Such branches have been supposed to indicate an eruptive origin for the jaspilyte, but it is necessary to explain them in some other way, consistent with many facts that demand the presence and active participation of oceanic water in the process of formation of the jaspilyte. The reader is referred to the fifteenth annual report for a discussion of the eruptive hypothesis and a statement of objections to it, and for an explanation of the dike-like appearances of some of the jaspilyte bodies.* These objections are summarized in another part of this bulletin. In brief, it is only necessary to say at this place that these branches from the ore bodies are supposed to be caused by the crumpling and breaking and squeezing of the entire rock structure of the country, by which some of the thinner sheets have been "buckled out" and thrust laterally among the enclosing green schist. Such angular displacements are seen on a grand scale among the argillytes and graywackes of the region, at some points on the south shore of Vermilion lake, on sec. 20, 62-15. Plate IV represents, by reproduced photography, the appearance of the so-called dike which is discussed in the fifteenth report. This view was taken in 1886 before the face of the bluff had been hid by the working which has since filled up that part of the mine.

Explanation of Plate IV.

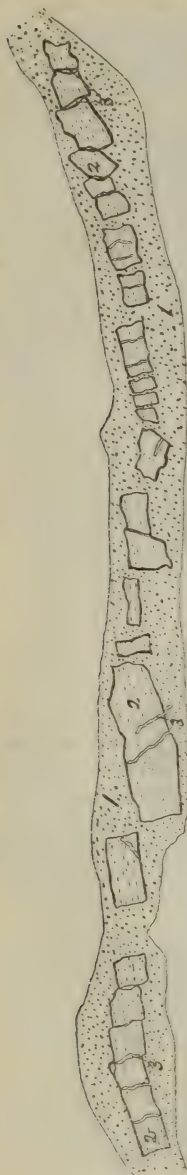
The "dike" is seen ascending perpendicularly across the face of the bluff, near the center of the view. Its width is about two feet, varying to four feet. It was visible formerly continuously from the surface of the ground downward to the first level, about 45 feet, and, passing under the ascending railroad track, could be seen crossing the schists in the same manner, and in the same direction, in the next lower level, about 35 feet deeper. The ore of which it is composed is not of first quality, but too siliceous. It shows distinctly the banding characteristic of jaspilyte. It is jointed horizontally as well as perpendicularly.

The surrounding schists are charged with iron peroxide and are entirely destitute of the usual fine schistose structure. They are coarse-grained, finely jointed near the "dike," but massive or irregularly cut into large blocks by joints, at more distant points. In close proximity to the "dike" they are much confused by close and irregular fissure planes.

Again, the curious, minute fracturing and repeated faulting of some of the individual layers of the banded jaspilyte, while those adjacent are intact, is worthy of note. One such is illustrated by the following sketch, figure 8, which represents the minute faulting of a band of brown jasper embraced in an unbroken band of hematite, drawn from nature near the opening No. 9, on the north

*Fifteenth Report Minnesota Survey. pp. 223-247.

slope of the north ridge at Tower. This is included in the space represented by Plate II.



Explanation of Figure 8.

No. 1. Narrow belt of pure hematite, about $\frac{1}{2}$ inch wide, embraced in hard jaspilyte, running about fourteen inches, so far as sketched, one of many similar sheets near adjacent.

No. 2. Broken and faulted brown jasper sheet, embraced entirely within the hematite of No. 1, the parts having once evidently formed a connected layer.

No. 3. Semi-chalcedonic quartz veinlets, apparently the original cement for the fragments of the brown jasper.

The width is exaggerated.

It appears that the jasper layer was fractured as represented, and cemented by silica (No. 3), and that subsequently it was faulted generally at the same places where it was before fractured, but that some of the original fractures were not faulted. After the faulting the whole was embraced in a later deposition of pure hematite, one of the ribbons that mark the large jaspilyte mass exposed here. The reader may compare Figure 60, p. 378, Fifteenth report.

It has already been shown that many pieces of the jaspilyte varying in size from the smallest appreciable fragment to large boulders, and even to pieces that seem not to have been moved very much from their native places, are disseminated through the green schist. Several were noted specially, and sketched in the summer of 1889, and such are illustrated in the eighteenth annual report.

In the highest of the tunnels of the Tower mine, which discharge southward, and also the most westerly, and at the southern end, is a north-and-south rock-cut, which seems to transect that series of thin layers of alternating jaspilyte and schist which occurs south of the Stone mine, at the railroad cut, already alluded to. This tunnel cuts across the bedding and the schistosity, and therefore the phenomena displayed here are the complement of those described at the other cut, which goes nearly parallel with the strike. Several important physical structures are emphasized

Fig. 8.



Breccia of Jaspilite cemented by Jaspilite

here by the appearances, that can easily be inspected on the face of the cut. (Compare the 18th annual report).

1. The jaspilyte is contained in the schist in lenticular masses, and in thin, interleaved, vanishing sheets that have thin, sharp edges upward and downward. This is most manifest in innumerable instances here within the horizontal space of thirty feet.

2. The jaspilyte is contained in similar masses that terminate east-and-west in the schist.

3. In the space of 22 feet, north and south along the face of this cut, can be counted 36 jaspilyte layers, varying in thickness from $\frac{1}{4}$ to 24 inches, all of them having at least six inches extent up and down, the rest of the rock being green schist, or jaspilitic red schist (or "shale" similar to rock 1547). Besides these there are some indefinite graywacken layers containing rounded pieces of jaspilyte as pebbles.

4. On the east side of the cut is seen the manner of termination of one of the larger lenticules of jaspilyte, in the midst of the schist, the exposed terminal end appearing unbroken near the track, though broken off at the top by the work of making the cutting. The shape of this western termination is represented by the figure below (Fig. 9), which shows a section across the lenticule north and south.

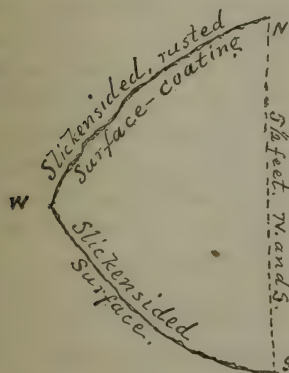


FIG. 9.—Western termination of a jaspilyte lenticule.

5. Within two inches of this large mass, sketched above, was a smaller, apparently concretionary mass of jaspilyte, about 18 inches in its greater (perpendicular) diameter, appearing on the face of the cut to be entirely surrounded by the green schist, and separate from the larger lenticule. In order to ascertain whether it was connected with the foregoing large mass, by means of a crow-bar it was dislodged entire and fell to the ground. It left a continuous concave socket, the exact imprint of itself, and was

coated and smoothed over its whole exterior in the same manner as the larger one, and was wholly independent and separate from it. It is numbered 1568. It is sharper, in cross-section, at the upper end than at the lower, and while about 18 inches in perpendicular diameter, it is only four and a half inches thick north and south, and eight inches wide (*i. e.*, E and W.) Several small

parts, broken from the upper end before it was dislodged, are also given this number. These show that the "egg" consists essentially of hard chalcedonic silica with a little hematite.

6. Within the tunnel, toward the north further, the green schist contains graywacken bands. In these are small pebbles of chalcedonic silica, but, in No. 1469, can be seen three ($\frac{1}{4}$ -in. thick) veins of chalcedonic silica crossing the structure of the green rock, at oblique and varying angles. This was taken from the roof of the tunnel, about fifteen feet from the southern entrance.

7. In No. 1568 the principal color-bands run across the face of the section, and are not wholly concentric. There is a series of accretionary bands surrounding these and enclosing them with an outer rusty coating, which gives color to the supposition that the egg is wholly concretionary. These outside bands fade off into the green schist structurally and mineralogically.

8. The mass itself appears to have been a fragment dislodged from its native place, and, while perhaps not yet firmly rigid, to have been imbedded in the materials that now constitute the schist, and with them to have suffered the pressure and upheaval that have brought the beds into their present vertical position. If it had become rigid before it was placed in the schists, it might still, perhaps, have been compelled to take its ovate form by reason of the pressure and the mechanical movements to which the

beds have been subjected. Judging, however, from the general ovate form of all the jaspilitic lenticules, even the largest, it seems more reasonable to ascribe this shape to some forces or circumstances that attended its origination, than to mechanical causes that operated afterward.

Another egg of jaspilyte, similar to that last described, appears in the midst of the schists near the so-called dike which is shown in plate IV. This is represented by the following cut, figure 10.

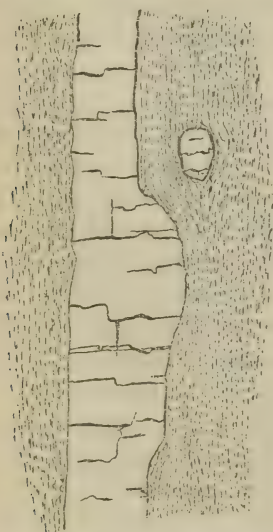


Fig 10. Egg of jaspilyte near the so-called dike. Old pit of the Stone mine.

The mined iron masses have no regular manner of alternation or position in the strata of the Keewatin. They appear suddenly and irregularly. They have no constant hanging-wall nor foot-wall. They cannot be followed along the strike for great distances. The largest jasper-ore masses are traceable not more than a mile and a half. Those that appear at the surface now are those that accidentally were so placed in the green schists at the time of the upheaval and fracture that, after glaciation, they are found exposed. There may be expected many others that have not been so exposed. They may be found by means of the diamond drill. Several have been so discovered at Tower by the Minnesota Iron Company. It has been noticed, however, that they are likely to be associated closely, and more numerous, with the massive portions of the formation, where the sedimentary stratification is least apparent. Such portions are the greenest, and the rock is a chloritic schist, or a "dioryte." It seems as if the accumulation of the green schist in its massive aspects afforded conditions more favorable for the accumulation of the ore. No ore bodies have been discovered in the typical sericitic schists, nor in the argillites, nor in the graywackes, nor in the sub-crystalline porphyritic bosses, nor in the glossy felstones or felsytes. The green rock that contains the ore is sometimes agglomeritic, as at Ely, but not conglomeritic.

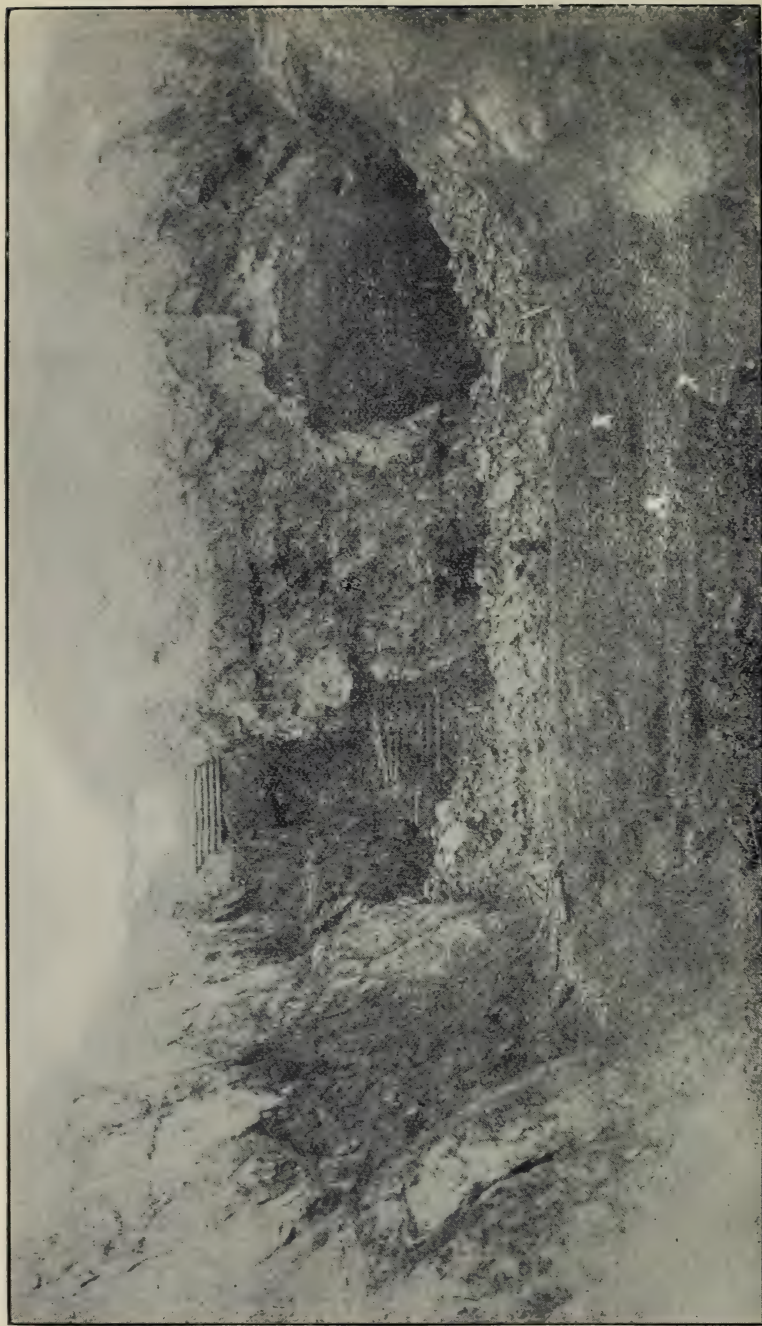
A map of the region embracing the ore ridges at Tower is seen in plate x. This indicates also the positions of some of the drill-holes recently made by the Minnesota Iron Company to ascertain the underground position and dimension of the ore-bodies. The contour lines of 1,600 ft., 1,550 ft., and of 1,500 ft. above average tide-level are shown approximately.

An examination of the tables already given of the diamond drill records of the rock strata as they changed from time to time in sinking the diamond drill, will be an interesting study for the geologist as much as for the miner. The core taken out by the drill in all cases determined the designations that should be applied to these strata. The names were given by the drillers under charge of Messrs. Prince, Cole and Wilcox, through whose coöperation and that of Capt. Williams much information relating to the physical structure of the ore bodies at Tower was received. These diamond-drill sections reveal frequent changes in the rock underground the same as has been described on the surface. The alternations are between chloritic schist, jasper, slate, "soap rock," "paint rock," quartzite, and ore. In one drill hole (T) a thickness of 312 ft. 5 inches of "mica schist" was reported at the bottom of the

exploration, the drilling having been in the same rock when it ceased, at the depth of 1,001 feet, but having inspected a sample of this, sent by Mr. Wilcox, it proves to be a soft greenstone, with coarse folia of chlorite, and without apparent free quartz.

North of the summit of the north ridge, yet within the main bulk of the ridge, the drill revealed a large body of fine ore which has since been entered upon by the mining company, and is producing largely. At numerous places, and at various levels in the drill holes, beds of ore were reached which had, so far as known, no representation at the surface. In the same way beds of jaspilite, more or less associated with ore, and some without any ore worthy of mention, were passed through. It appears therefore that, while the ore-bodies are frequently associated with the greenschist, in its most massive conditions, they are not placed in it in any recognizable order. They are *grouped* in greater frequency along some belts. They have the form of lenses, running to edges and vanishing in all directions. The belt of iron-bearing green schist is very wide at, and south from, Tower, and it is possible that at greater depths the bodies of merchantable ore will be found to have shifted their geographic position with respect to the "ridges" in which they are now mined, and may be at some distance south from Tower. The present surface topography coincides with the comparative resistance to erosion presented by the different rocks. The ridges are ridges because they are firmer and harder. The swampy spots are low because they are, at the surface, underlain by the softer rocks. But had the destructive erosions of the past, and especially that of the Glacial epoch, been carried on to the depth of 500 feet further, or ceased 500 feet higher up, there is no doubt that the present *North ridge* would have presented a very different aspect, and it is quite likely that it would not have an existence at all in its present latitude. It is probable that the jaspilite masses which give it existence would have been either wholly destroyed, and that in their geographic places soft green schist strata would prevail, or that they would be still buried hundreds of feet below the natural surface. But it is equally probable, had erosion ceased sooner, or had it been carried further, other ridges would have been protruded similarly above the natural surface, carrying equally remarkable bodies of hematite.

It has been stated that there is in general, no recognizable stratigraphic order in the ore bodies, but that they are placed helter-skelter in the green schists, only being larger and more abundant along certain belts of country characterized by such schists. Yet in the practical mining of the ores at Tower, Capt.



IRREGULAR VERTICAL TRANSITION OF THE JASPILYTE TO IRON ORE AS DEVELOPED IN THE STONE MINE, TOWER. (P. 63.)

R. J. Williams is of the opinion that, within certain limits, he has recognized a general principle of what he calls "right-handed throw." That is, when in course of mining an ore body ceases toward the east or west, along the strike, it is likely to recur again toward the right obliquely from where it disappeared, if it exist at all. This rule he thinks has been sustained in a majority of instances that have come under his observation. As the general strike, as seen on the surface, ought to agree with this succession of lenses below the surface if it be true, such a law ought to be expressed in the succession of lenses at the surface, but it has not been observed. It would indicate that toward the east the ore bodies are gradually crowding toward the south, relative to the body of the green schist, and toward the west that they are crowding toward the north. If this principal be true it has one marked exception at Tower, viz: The north ridge, which is a large lens of ore and jaspilyte, lies east of the meridian of the south ridge, yet it illustrates a *left-handed throw*, since it is further to the left obliquely from the east end of the south ridge.

There is, however, a well-substantiated instance of vertical transition on a large scale from worthless jaspilyte rock to merchantable ore. This was in the Stone mine (No. 4), and a photograph of the spot is poorly reproduced in Plate VI. In the plate a column of jaspilyte is seen standing near the center of the plate rising to the surface. This was left because it was not ore, but on the second level, about 50 feet lower, it was found that this column, in the regular line of its strike downward, afforded good ore. At the bottom of the plate, in the foreground, in the original, a mining scene is shown (at the crosses XX), but this is not brought out in the plate. This change is due to a variation in the rock as an ore-carrier, and not to a bodily transition of the ore and rock to a different plane. In the same plate, further to the right, another remarkable vertical transition is shown. This change is more sudden. The overlying jasper roof, which rises to the natural surface, was found to cover a large mass of valuable ore, which in the photo is shown to have been removed. The same is illustrated by figure 11 below. The same transition from ore to jasper has been noted at Marquette by Prof. R. Pumpelly (Tenth Census, vol. xv, p. 8).

Figure 11 shows the appearance of the west end of the Stone mine (Shaft No. 3), as it was in July, 1889, (also shown imperfectly by photo-plate No. 6). The jaspilyte mass which presented at the surface a broad exposure (N. and S.) suddenly, at about 20 feet below the surface, narrows to less than one half the width it has at the surface and in its place is found a large body of good ore. Between this ore and the overlying jaspilyte there is a sudden passage,

as if there had been a bodily displacement. But no such sudden transition

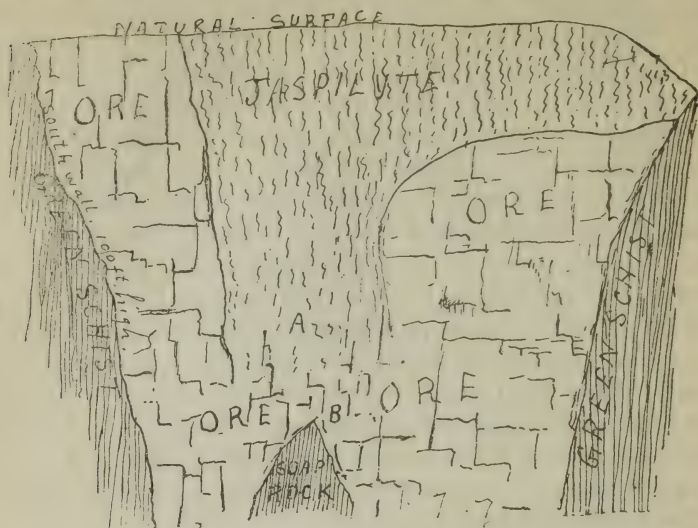
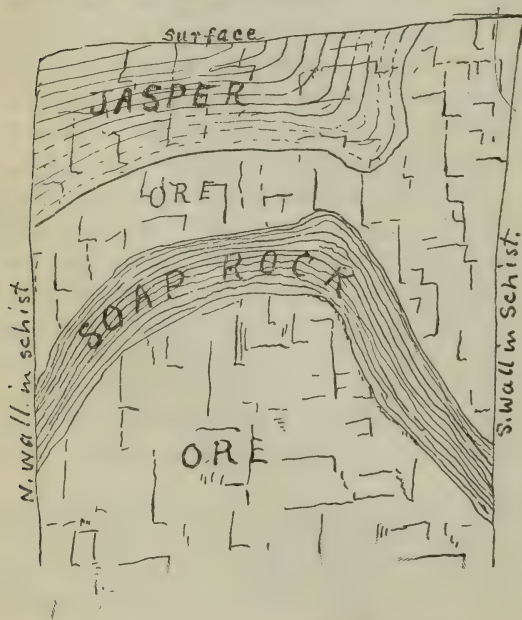


Fig. 11.

appeared between the jaspilyte at A and the ore at B. In the drawing (fig. 11) another feature is seen which could not be brought out in the photo, viz: a wedge-shaped mass of greenish soap rock, like that in the walls, is found to protrude upward into the ore. This had not been sufficiently uncovered to reveal its size nor its shape any further.



Other alternations were seen in the W. Ely mine (No. 6). It is frequently noticed that the soap rock divides ore from jasper, or ore from ore indiscriminately, and hence is no argument against ore and jasper being of similar and cotemporaneous origin.

Fig. 12 shows the east end of the W. Ely mine (No. 6) in July, 1889.

Fig. 12. East End of the W. Ely Mine (No. 6) in July, 1889.

Both walls are in soap rock, but the north wall also has some jasper. The figure shows an irregular, transverse, but upwardly flexed, series of strata

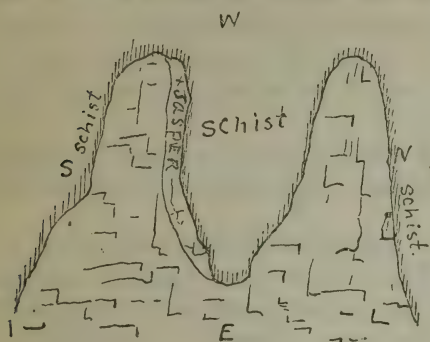


Fig. 13. W. End (under ground) of the W. Ely Mine (No. 6) showing Alternations of Lenses of Ore and Soap Rock.

at Vermilion lake, the ore body becomes narrow toward the east, and evidently gives out in a downward direction. At least a drill which entered the hill on the south side struck the ore bed south of where it is now mined, and did not find it beneath its present outcrop. It is as if there were a horizontal fault as shown in figure 14.

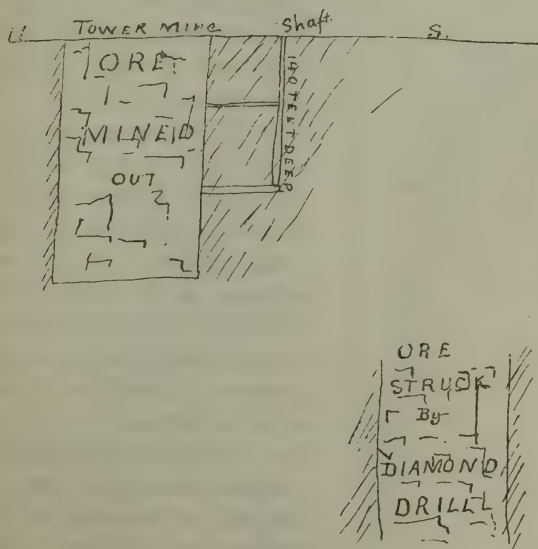


Fig. 14. Perpendicular Section of the Ore Beds at the Tower Mine.

Some further information may be gained of the shapes of the ore-bodies by examining the ground plans of some of the mines,

viz: Plate XII represents the plan of the No. 3 pit (old Stone mine). Plate XIII represents the same for the No. 5 pit (old East Ely mine). By these it appears there is a slight downward inclination toward the north. Plate XIV represents the plan of the Pioneer mine at Ely. It cannot be ascertained by this that there is a dip in any direction.

At Ely the Chandler mine ore lens has developed a curious shape as the mining has progressed. This shape is illustrated by Fig. 15.

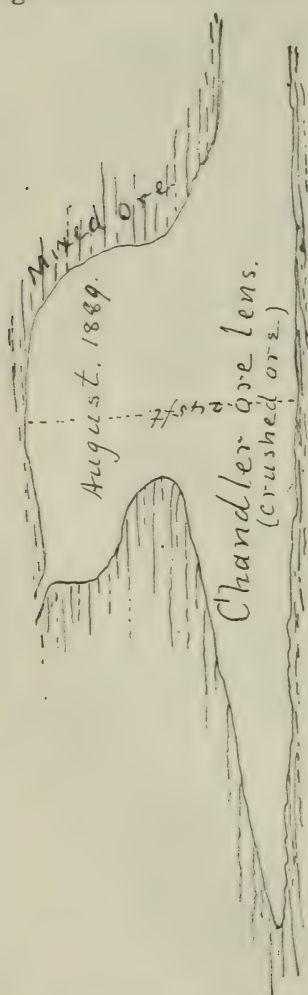
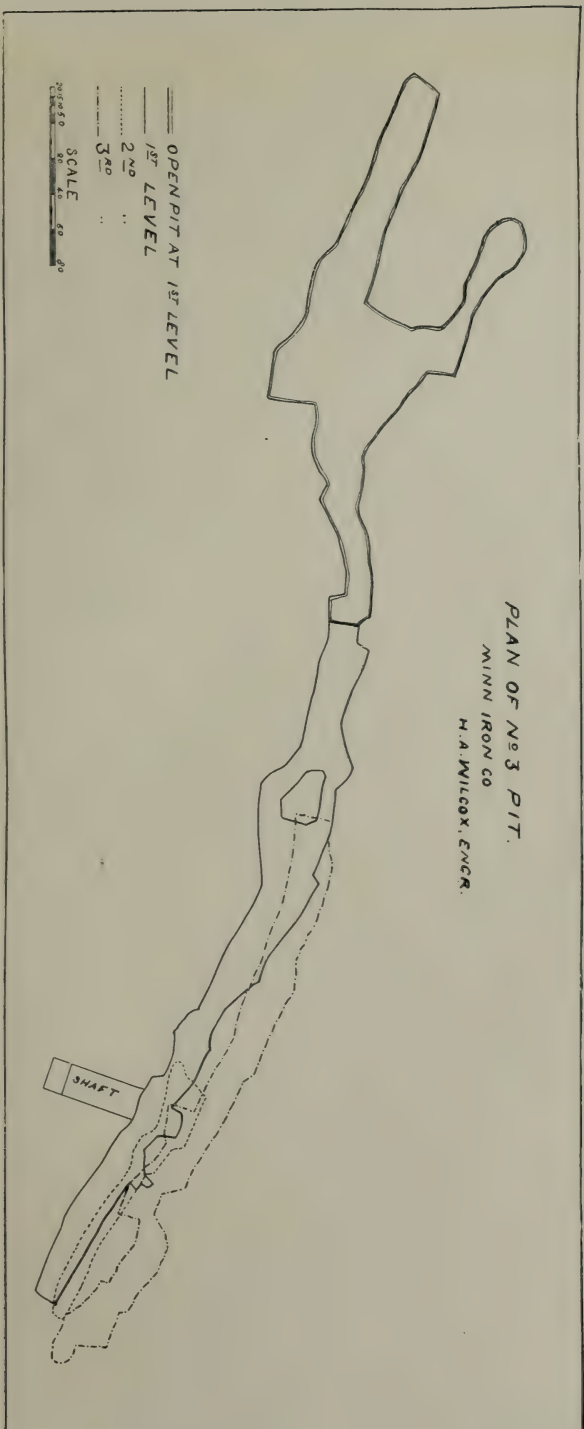
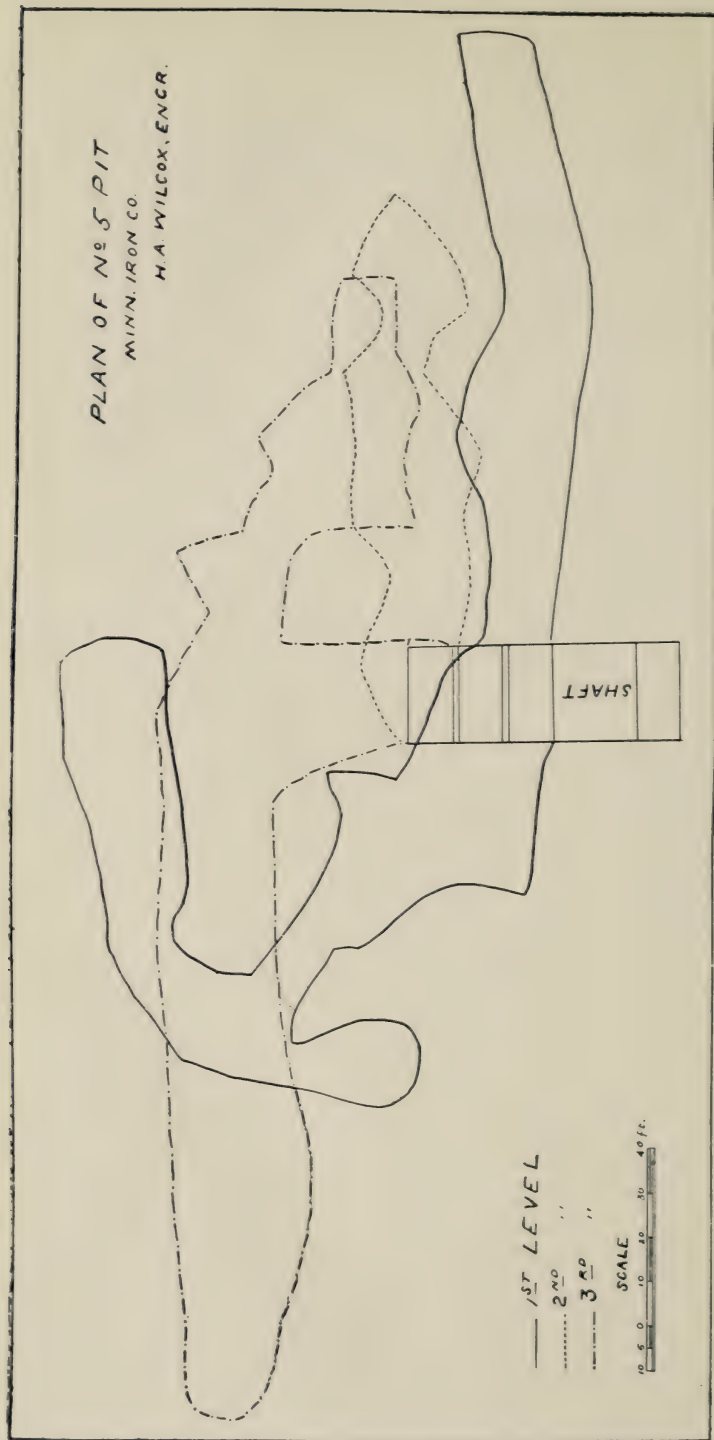


Fig. 15. Shape of the Chandler Ore Lens, Ely, as developed in August, 1889.

The ore of the Chandler mine is a fine Breccia from which the original cement (perhaps siderite principally) has been removed. It lies loose in its place and can be mined cheaply. Diamond drills have cut the Chandler ore 300 feet from the surface. It is still crushed at that depth. Shaft No. 1 goes down 190 feet in the foot-wall of greenstone. The first level is 80 feet deep. The second is 60 feet deep, and the third is 60 feet below the second. At one place the ore bed is 245 feet wide, and it averages about 90 feet wide for 800 feet length. The ore is very uniform in purity and per cent. of iron. Although the ore of this mine is crushed to the total depth to which it has been explored, it grows more solid toward the walls, particularly toward the foot-wall (south). There are bands or streaks in it which show the same folded or contorted structure as that usually seen on the surface of an exposure of jaspilite. The ore is quite open to the action of percolating water. Many faces of the angular fragments are covered with a shiny black deposit of limonite which if it were thicker would form grape ore. A white mineral, probably the same as that described at Tower, is seen in seams in the ore and in the "paint rock." Streaks and beds



PLAN OF NO. 3 PIT, MINNESOTA MINE. (P. 66.)



PLAN OF NO. 5 PIT, MINNESOTA MINE. (P. 67.)

of varying thickness of "paint rock" are found all through the ore, running in nearly all directions, but usually in the general strike of the ore. There is no doubt about this ore being the same as that at Tower. It has simply been crushed by pressure, flexure and movement. There are many large lumps of ore mingled with the smaller. Sometimes—in the east end of the mine particularly, and there only on the first level—the crushed ore is mixed with much jasper and rock, and is rather lean. The ore, however, becomes better on the lower levels.

At Tower a similarly brecciated or crushed condition of the ore is occasionally met with. On the third level of pit No. 5 (East Ely) is a stratum of such ore about three or four feet thick.

(2.) *Mineral associations of the hematites of the Keewatin.*—The mineralogy of the iron mines at Tower has not been carefully studied, and we cannot say yet what number of interesting accompanying minerals may exist. From the three main constituents, the green chlorite schist, the silica and the hematite of the jaspilyte, there is every reason to expect many combinations and modifications have been produced by the physical changes and chemical reactions that we are led to believe they have been subjected to, in the long history through which they have passed. The profound physical and chemical changes, however, to which it is evident the rocks of the region have been subjected, took place mainly in Archean time, and ceased in primordial time and left the strata very nearly in the mineralogical and structural condition which they now manifest. There has been no later, widespread, metamorphosing action. There has been only the slight surface action of meteoric forces, penetrating to the depth of a few feet, not probably exceeding, since the Glacial epoch, even in the permeable schists, 50 feet below the surface, and generally not exceeding 10 feet. As Archean time left the rocks, substantially so they have remained, excepting only so far as they have been disintegrated and degenerated by extraneous weathering and erosion which may have carried away several hundred feet from the surface.

It is evident, therefore, that the mineral species are of two kinds. (1) Such as are indigenous to the formation, and date from Archean time; and (2) such as are of secondary and subsequent origin.

The *indigenous minerals* are essentially chlorite, muscovite, quartz (chalcedonic) and hematite, with orthoclase and plagioclase occasionally disseminated abundantly among the pressed and sub-crystalline schists. There are also variations in the schists to calcareous, dolomitic (?) masses which are constituent parts of the

Archean rocks.* But, in the schists, the foliated minerals, muscovite and chlorite, are those that give character and color to the bulk of the Keewatin. That these minerals date from Archean time is shown by a consideration of their behavior with respect to the structure and with respect to other minerals. They participated in the upturning, folding and shearing action which everywhere distinguishes the Keewatin, and that action was practically complete before the advent of the Taconic (Animike), for the structures that it caused are seen to pass in their perfect development beneath the unconformable strata of the Animike. These minerals do not fill fissure-veins formed since the hardening of the rocks, but they constitute rocks that were crowded together, when once plastic, so closely, and so kneaded upon themselves that the smallest cavity that may have existed has been filled, the shapeless foreign pieces have been drawn out into some uniformity of elongation by some great force that acted over many square miles, and the easily molded parts have been compelled to adjust themselves to the forms of the rigid. Where the pressure and shearing was sufficient to produce plasticity, the green schists have become hard and sub-crystalline, and have taken on the role and the structures of igneous rock. Several instances of this have been recorded and fully described.† The resulting rock is massive, but when it has not been squeezed out of its place it shows on weathered surfaces the banding characteristic of sedimentary structure. When it has been displaced it mixes with the unplastic fragments of the original strata, filling their interstices and wrapping about them, and on solidifying taking a basaltic structure. It seems to be an imperfectly developed syenite, and indicates the probable origin of larger syenite masses and ranges such as that of the Giant's range. It is in these sub-crystalline masses that are seen imperfectly shaped crystals of orthoclase and of plagioclase.

The *secondary minerals* are such as have been produced by the decay or solution of the indigenous minerals and the redeposition, by mineral waters, of the chemical solutions in fissures, cavities and all interstices in the original rocks. The alteration products sometimes are abundant. They produce calcite, dolomite, pyrite, vitreous quartz, limonite, specular hematite and siderite. Calcite, limonite and dolomite seem to have been produced in some cases since the consolidation, by recent weathering, and are apparently increasing in amount. But pyrite, vitreous quartz, hematite and siderite are of older date. They are found in deep-seated breccias

*Fifteenth Report, p. 371; Sixteenth Report, pp. 95, 316.

†Fifteenth Report, pp. 267 (rock 868); 316 (rock 1, H.); 352-355 (rocks 990-995).

and in fissure veins, and are due perhaps to disturbances that affected the Keewatin rocks after their consolidation and perhaps at the epoch of the Taconic (Animike). Pyrite, especially, seems to have been of very early date, since it occurs in some places in large quantities deep in the mines, and as bright cubic crystals (as on Stuntz island) in pure, white, chalcedonic pebbles which are involved with other boulders in the Keewatin agglomerates. Through its decomposition and the decay of chlorite and siderite, large deposits of limonite are produced.

Without attempting here to carry the distinction between the minerals and ore masses any further than to separate between *primary* and *secondary* products, it will be sufficient to call attention to two epochs of brecciation that are exhibited by the jaspilyte, each of which must necessarily have its distinguishing mineral characters and associations. The first of these breccias was coeval with the production of the ore and jaspilyte. It has been referred to and illustrated (see figs. 6 and 8) in describing the structural characters of the ores, and is further represented by plate XI, which is from a photograph of hand-samples collected at Tower. This breccia is characterized by being re-cemented by materials like the rock brecciated, generally by chalcedonic silica, the resulting mass being as firm as any part of the country rock. In several instances during the progress of the investigation of the ore-bearing rocks of Minnesota some puzzling and apparently anomalous occurrences of chalcedonic silica in the form of veins have been noticed. One is mentioned south of Fall lake,* where veins of chalcedonic quartz were seen cementing a breccia of jaspilyte. In 1888 other samples were seen of the same structure, some on the South ridge, near the Lee mine, and some on Chester peak. These are referred to in the eighteenth annual report, pp. 28-35. In the light of further study, the result of which is given above, these occurrences are no longer problematical. It has been seen that a frequent brecciation contemporary with the deposition of the jaspilyte is one of the characteristics of the ore and of the jaspilyte, the cementing material being produced by a recurrence of the same forces as produced the original strata, and necessarily causing it to enter and permanently fill all the cracks and cavities that might have been left after the brecciation. As to the origin of this chalcedonic silica, it is believed to have been a chemical precipitate from the oceanic waters of Keewatin time. That subject will be discussed in another part of this bulletin.

Another brecciation took place after the jaspilyte and ore and

*Fifteenth annual report, p. 324. Rock sample 1013; also p. 245.

foregoing breccia had been formed. Its cementing minerals are crystalline, and often quite coarse. They are hematite in bright tabular flakes, vitreous quartz, (sometimes in large crystals,) pyrite and siderite. These minerals, when coarsely crystalline, and pertaining to this period of fracture, are seen to fill fissures that cross the jaspilyte and ore masses in all directions. These later veins also cross the veins and breccias of the former brecciation. But no veins of chalcedonic silica cut these. This second brecciation gave origin to a set of secondary minerals, but, though the hematite that is of this age, and also the siderite, are valuable by reason of their purity, as ores, and sometimes by reason of their quantity, they cannot be considered an important portion of the Keewatin ores, and in no case should be considered as elements in the problem of the origin of the ores of the Keewatin.

If now this be pushed still further, and we inquire when this second brecciation took place, we have only scant data to reason from. A brecciation and cementation which so deeply affected a great formation—for it operated on the schists and slates of the Keewatin no less than on the jaspilyte and ore—must be explained by resort to some force of wide extent and long duration. It must have been of the nature of the earthquake and the volcano, and it must have operated in such proximity to the phenomena observed that its effects could be disseminated through the rocks concerned. These considerations point only to primordial time. The Taconic age, which followed next after the Keewatin, represented by the next overlying (Animike) rocks and the rocks of the Cupriferous, was agitated, in northern Minnesota by earthquake disturbance and volcanic phenomena. This is evinced not only by the nature and positions of the rocks of the Animike and the Cupriferous, but by the occurrence of many dikes of fresh trap-rock referable to that age, which cut across the strata of the Keewatin, and which have been noted in all the Minnesota reports.* These later dikes vary in width from a few inches to fifty or one hundred feet, and they are found, in greater or less frequency, throughout all that part of the state underlain by the Keewatin, and are not uncommon in the rocks of the Vermilion and the Laurentian. There is no other known adequate cause for such a fracturing of the older rocks as is seen in this second brecciation. Later periods of disturbance, fracture and upheaval are known in other parts of the country, some that followed the Trenton, some that followed the Carboniferous, and some that occurred during and after

*Dr. A. C. Lawson has suggested that some of the eruptive rock of the Rainy lake region dates from the age of the Cupriferous.

Mesozoic time. But the *loci* of all these, so far as known, are more remote. It is more reasonable to invoke a cause that is near at hand, when it is sufficient, than to seek for a more distant one. Therefore we may, for the present, refer the date of this second brecciation to that cause which lies nearest, and place it in primordial time.

It will be necessary to remark, in conclusion, in relation to the minerals that are found associated with the Keewatin ores, that a tertiary condition of the ore is found, in considerable quantities, sometimes, and affording merchantable products. It is limonite. This is derived very largely from a change in the pyrite and the siderite of the second brecciation, but of course augmented by any process of decay that may be now going on in any of the original ferruginous minerals. This is a natural effect of exposure to atmospheric forces, and while it may have been in progress during all post-primordial time, it is certainly in progress at the present time. Its earlier products were removed by the glacial abrasion, and those that now exist may be referred reasonably to post-glacial time. This limonite fills or partly fills some large cavities and is frequently found lining smaller ones with its botryoidal and stalactitic forms.

(3.) *Microscopic Characters of the Jaspilyte.*

PLATE VIII.

As the green schist embraces the jaspilyte, but very rarely shows a graduation into it, on the contrary the jaspilyte contains the iron ore and continually shows graduation into it. It became therefore, one of the interesting and important problems of this investigation to learn the origin of the jaspilyte. The method of origin of the silica, which constitutes the great bulk of the jaspilyte, was found to be inseparably bound up with that of the hematite. Numerous facts and considerations based on a careful examination of the physical relations of the jaspilyte to the ore and to the enclosing schist, with illustrations, have been given pointing to the origin of the iron and the silica from chemical precipitation from the oceanic waters of Keewatin time. It was necessary that every light possible that could be thrown upon this inquiry, whether from chemistry or microscopy, should be brought to bear on the problem.

It was seen at once that chemical analysis of the jaspilyte, as such, would be of no avail, since the rock is seen to vary, microscopically, from pure silica to pure hematite, a thousand times, and that all degrees of predominance of one over the other could be selected. The analysis of the ores themselves was studied in order to ascertain the nature of the prevalent impurities, and their per-

centages compared with those of other ores. Many of these analyses are given beyond (under *Quality of the Keewatin hematites*) and the bearing of the presence of the different impurities in their different amounts, as compared with other ores is discussed in the chapter on the origin of the Keewatin ores.

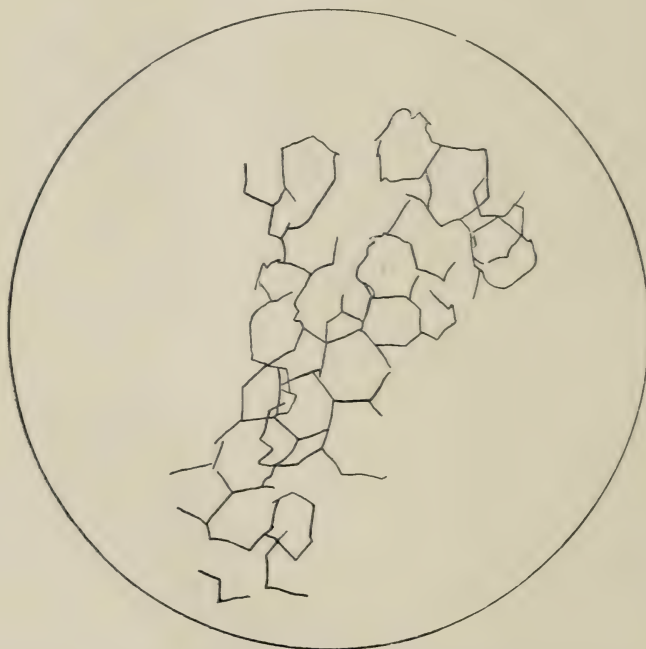
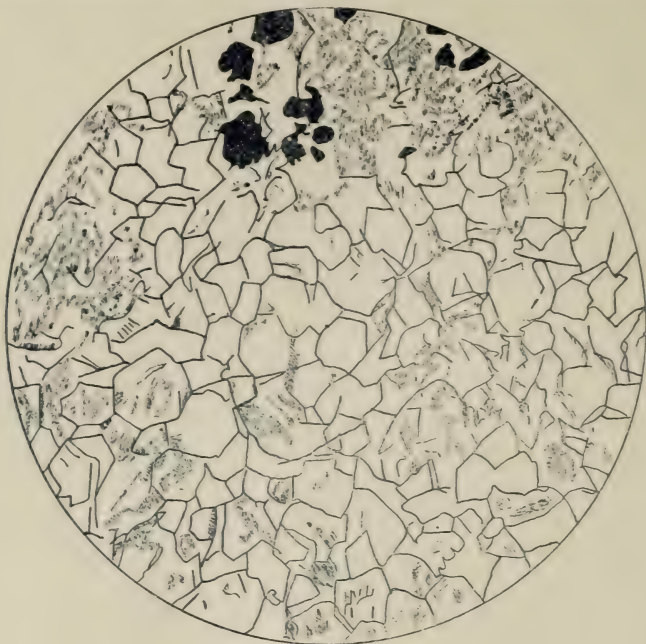
The microscopic examination of the jaspilyte was directed specially to the question—Is there evidence, pro or con, as to the siliceous ingredient of the jaspilyte being the result of chemical precipitation in oceanic water? Dr. Hensoldt has carried on this examination in our laboratory, and with frequent personal conversation and discussion between us. Numerous thin sections and all the field specimens were available for the purpose. The result, which is given below in Dr. Hensoldt's language, confirms unequivocally, and establishes the chemical precipitation theory of the jaspilyte.

There are three microscopic features which the minute grains of the jaspilyte present, which can be explained only on the supposition that the silica was chemically precipitated, and one of these indicates its precipitation in oceanic water. They are well described below:

Jaspilyte.

Rock 867.—The hand specimen from which this section was prepared is composed of layers of a dense, whitish silica, alternating with layers of hematite, which average an inch in thickness. The lines of contact are sharp and distinct and no trace of gradual transition is anywhere observable. The jaspilyte layers are, practically, homogeneous throughout, but the hematite strata exhibit numerous cracks and fissures, which are filled with the same siliceous material which constitutes the jaspilyte. The significance of this feature will be shown later on.

Under the microscope the section of jaspilyte reveals a structure which might be termed "crypto-crystalline," but which differs completely from that of any ordinary massive or fragmental quartz-rock. Instead of angular or rounded grains cemented by an interstitial substance, as in sandstone, or "vitrified" by pressure, partial fusion or siliceous infiltration, we have here silica in a finely divided condition, such as can only be accounted for by chemical precipitation from a saturated solution. Under a magnification of about 60 diameters the section presents the curious "mottled" structure which characterizes certain siliceous deposits, such as the well known novaculyte of Hot Springs, Ark., and which has never yet been observed in crystallized quartz. It would seem as if an immense number of siliceous particles—



SHAPES AND DISPOSITION OF THE SILICA GRAINS.
ROCK 867. (P. 78)

neither partaking of the character of crystals, granules or angular fragments—had been accumulated and cemented, not by an interstitial paste, but by superincumbent pressure. Many of the siliceous particles are colorless or nearly so, while others are more or less clouded by an opaque dust-like substance, probably magnetite. At first it would appear as if each constituent granule we will retain this term for the sake of convenience) had been part of an originally homogeneous matrix of amorphous silica, such as flint or jasper, which through heat or pressure became partly disintegrated and traversed by an elaborate network of minute cracks. Thus the granules would have resulted from a mere subdivision of the homogeneous matrix by means of fissure-cleavage. But if we examine our section with a “half-inch” objective we are startled to observe that many, if not most of the granules show a remarkable uniformity in size as well as outline. Instead of irregularly bounded fragments of the most varying dimensions, such as we would naturally expect in fissure-cleavage, we behold particles of nearly uniform size and more or less *hexagonal boundaries*. In many instances the hexagonal outlines are of extreme regularity (see plate VII); in others considerable distortion is noticeable, but as a general rule they are persistently manifested, even in the closely joined or welded portions of the mass.

That these siliceous particles are not sand-grains, as one would be tempted to infer from their appearance so far, can be clearly proved in two ways, viz:

1. By their behaviour in polarized light.
2. By the absence of fluid enclosures, which invariably occur in crystallized silica.

If the particles were “crystallized sand-grains,” viz., sand-grains transformed into symmetrical crystals by a secondary deposition of silica, or if they were fragments of an originally crystallized or crystalline quartz (whether the constituent of some ancient granite or otherwise) then each individual granule would only show one uniform tint between crossed nicols, viz., either blue or yellow, unless the granule happened to be cut at right angles to the optic axis, in which case it would only give four extinctions. In this jaspilyte, however, each granule invariably exhibits *several* colors, which, on rotating the lower nicol do not change in the normal order of crystallized quartz but seem to turn around a central point, precisely as we see it in chalcedonies, jaspers, agates and other amorphous silica. In the novaculite of Hot Springs, which is a chemical precipitate of silica, we observe the same phenomenon.

The second line of proof is even more conclusive than the first.

No crystallized quartz has yet been discovered in which fluid-enclosures are not more or less abundant. Minute cavities, containing water, saline solutions, hydro-carbons or carbon dioxide are formed even in the clearest rock-crystal and occur in millions in the quartz of all granites. "Smoky" quartz is full of them and the whitish color of the so-called milky quartz is entirely due to the presence of myriads of cavities. Now the quartz granules of this jaspilite are entirely free from fluid lacunæ of any sort and even the most careful search, under high powers of magnification, will not reveal a single cavity. We also look in vain for fluid-cavities in agates, chalcedonies, jaspers and the novaculite already referred to; thus we cannot be far wrong in attributing the formation of the granules of the jaspilite to a non-crystalline source.

But then, if these granules are amorphous silica, how can we account for their hexagonal outlines? There we are at once confronted by a fact which, if correctly interpreted will furnish a key to the entire mystery of this jaspilite formation. In the writer's opinion there can be but one answer to this question. The silica which now constitutes the jaspilite was chemically precipitated from a solution. What the character of this solution was, will perhaps never be even approximately determined, and is immaterial for the purpose of the present inquiry. The silica may have been contained in the heated waters of an ocean, charged with hydrochloric, sulphuric and other acids, an ocean such as this globe will never know again. Where the silica *originally* came from will also remain a subject for speculation. Enough that it was precipitated, and moreover in a gelatinous condition, viz., in the shape of minute globules. There are strong grounds for believing that these globules were perfectly round or spherical, and that their accumulation was a slow and protracted one. Soft gelatinous globes or spheres composed of any yielding or pliant substance, when superposed or otherwise compressed will *invariably* assume hexagonal outlines, as can be easily verified by experiment.

Thus whatever line of inquiry we may follow—and it must be borne in mind that the methods at our command, in this instance, are necessarily restricted—we are driven to the same conclusion, viz., that the silica of the jaspilite is a chemical precipitate; and in the writer's opinion this point is clearly established.

In reference to the origin to the hematite layers, which are so regularly interstratified with the jaspilite deposits, the microscope, for obvious reasons, can give us no material assistance. But reasoning from all the data in our possession, there cannot be the shadow of a doubt that their precipitation took place in precisely the same

manner which characterized the formation of the jaspilite. The silica of the latter and the iron of the former were contemporaneous in their origin and the order of their deposition was solely determined by gravity. Let us assume that both the silica and hematite were once the constituents of a basic lava or volcanic ash, ejected by one or more submarine volcanoes in pre-Huronian times. That most, if not all volcanic outbursts in that remote period were submarine cannot well be doubted, as we have no evidence of the existence of dry land previous to the Laurentian age. The earth's crust was considerably thinner then and disturbances of a volcanic nature must have been of far more frequent occurrence than at the present day. It is now very generally admitted that the iron which we find on or near the surface—no matter in what form—was originally derived from deeper-seated regions in the interior of our planet and was brought up by volcanic agency, as a constituent of lavas and similar eruptive products. All eruptive rocks, whether basic or acid, contain iron in some form, usually as magnetite, though titaniferous iron and chromite are also extremely abundant, and the Ovikak basalt, which is the most basic of all known rocks, contains an enormous quantity of metallic iron. Then there are the iron silicates, such as augite and olivine, of which all basic lavas are very largely composed. Let such a lava come in contact with the heated waters of an ocean, heavily charged with hydrochloric, sulphuric and other acids, such as we know *must* have been the condition of the ocean for ages in the earlier history of our planet (unless we abandon the entire condensation-hypothesis) and a comparatively rapid and complete solution of the components of our basic lava, or volcanic ash, was unavoidable. The iron of the magnetite, being easily soluble in H Cl, was first deposited in the form of a soft mud, by reason of its greater gravity, to be followed by the silica, which would probably occupy a much longer period for its complete precipitation. There are grounds for believing that the first deposition of gelatinous silica did not take place till long after the formation of the hematite stratum and that the latter was repeatedly disturbed by upheavals and subsidences on a minor scale, causing numerous local distortions and cracks in the dense hematite mud which were subsequently filled by the gelatinous silica.

What became of the calcium and magnesium contained in the pyroxenic and feldspathic constituents of the original basalt, might well be urged in objection to our hypothesis, but a moment's reflection will show that their absence is really easier to account for than would have been their presence in the rock under examina-

tion. These elements, by reason of their lesser gravity, were kept much longer in solution by the water, which, moreover, was of far greater density than any of our present oceanic or lacustrine waters; thus they could be easily drained off by currents and deposited as magnesium and calcium carbonates—dolomites, marbles, limestones, calcite—in localities more or less remote.

Periods of comparative quiescence must have succeeded each volcanic outburst, as evinced by the regularity and uniformity of the interstratification of the hematite and jaspilite, and we must necessarily assume as many separate eruptions or successive lava-flows as we have layers of amorphous silica alternating with iron ore.

Hand-specimen 867, which has furnished the material of our section of jaspilite, has been selected as very typical of its class and as fairly illustrating the points and problems here discussed. The microscopical structure of the numerous samples of jaspilite examined by the writer, some of which were from localities many miles apart while others had been found in close proximity to each other, was practically identical so far as the essential features are concerned. In some instances the siliceous granules had been so firmly compressed or welded together that their individual outlines were more or less obliterated, so that the entire mass presented the dense, compact appearance of most of the Hot Springs novaculites. In others the structure almost approached that of certain fine-grained sandstones, so clear and distinct are the component granules.

Rock 1568.—A massive reddish-gray jaspilite, almost identical in its microscopical structure with that described under 867. The component granules are, however, exceedingly small, but with a good "quarter" objective their outlines can be clearly distinguished in the section, and we observe many symmetrical hexagons, as in the other varieties of this remarkable rock.

The sections of jaspilite which are illustrated in plate VII, showing the shapes and deposition of the siliceous grains, and to a considerable extent also those seen in plate VIII, showing the coloration of jaspilite between crossed nicols, are affected by the confused "aggregate" polarization resulting from the overlapping of the individual grains. Sometimes in making the drawing of these sections it is found difficult to distinguish and outline the shapes of the separate grains. By changing the focal distance of the microscope, by a very small movement of the micrometer adjustment, not only do the shapes which were before dim or which faded out entirely, become susceptible of delineation still

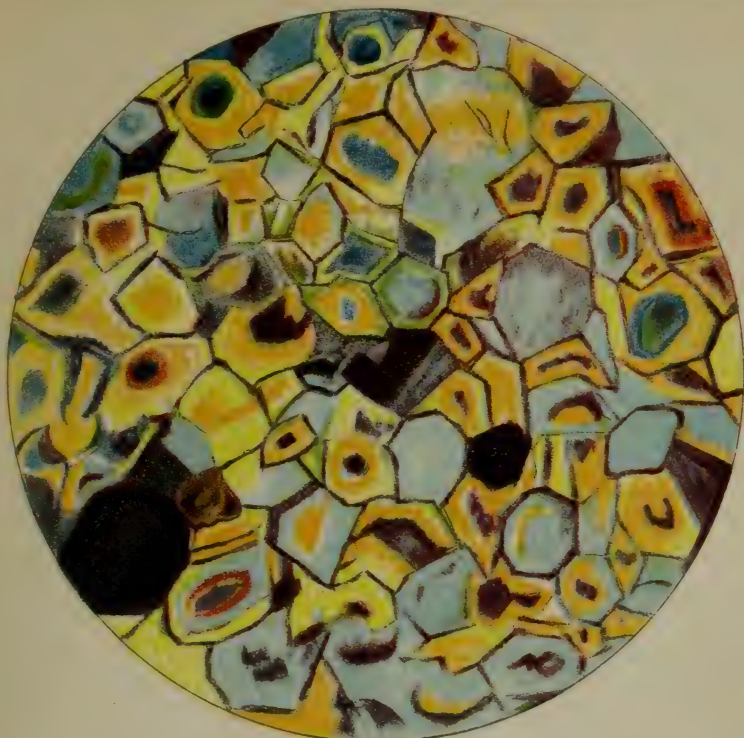


FIG. 1.
Rock 667 $\times 300$

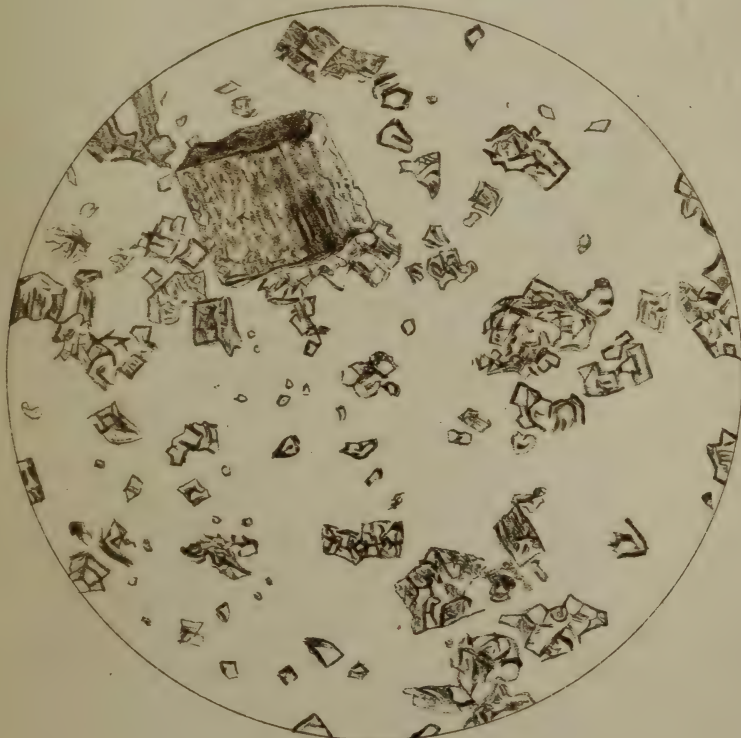


FIG. 2.
Rock 1565 $\times 300$

further, but other angular outlines which were at first indistinct or only seen along one side or angle, not belonging to the same silica grain as those already drawn, make their appearance more systematically, and by still further moving the micrometer adjustment, there comes into view a new set of more or less hexagonal grains. Of course the thinner the section the less there is of this interference, but in none of the sections made by us has this difficulty been found wanting. It is most pronounced in the preparation of the colored figures on plate VIII, because some of the shapely grains seen in ordinary light become divided, between crossed nicols, into several differently colored parts due to the refraction of the slightly underlying or overlying grains.

As explained in the description of the structural relations of the jaspilyte, there are some places where the jaspilitic element, i. e., the chalcedonic silica, is somewhat mingled, microscopically, with the element of the green schist. Although the change from one to the other, as seen in the field, is usually quite abrupt, yet there is occasionally a mixing together of these elements in one stratum.

When we come to examine the thin sections we find that there is frequently a sparse microscopic dissemination of the elements of the green schist through the jaspilyte. The figures seen in plate VII were drawn from sections of jaspilyte that do not contain any of these foreign grains. No mention is made of them in Dr. Hensoldt's descriptions, he having purposely confined his examination to those sections which furnished the problem of the *origin of the jaspilyte* without any entangling attendants, and hence to the pure chalcedony itself. In the section of rock No. 511 A (H), may be seen lying adjacent to the wavy, or somewhat ragged edge of the green schist, yet wholly within the jaspilyte, a few flakes and slender fibers of the green schist, and some projections of the schist, in the form of long fibers embraced among the silica grains. These fine detached parts are nearly colorless, whenever rotated between crossed nicols, particularly when they present some angularity, or outline that might be considered the result of some transformation in the crystalline structure. As they are followed into closer and closer proximity to the schist border they are multiplied in numbers and assume the usual green tint.

These fibers from the green schist should not be confounded with another colorless ingredient that is more abundantly scattered through the jaspilyte. This is in the form of microscopic grains and aggregates of grains. It is common in rock No. 511 A (H), but much more common in rock No. 1565, which is described microscopically as a flinty, gray or dark-gray jaspilyte from the shaft

at the Breitung mine (No. 12). These grains, which do not become fibers, although generally of irregular shape, yet have a tendency to rhombohedral outlines. Their nature is not definitely ascertained. They remain light even under complete rotation between crossed nicols. They show no dichroism, so far as observed. They may be dolomite, and were apparently chemically precipitated in the same manner as the silica. They cause the opaque whitish-gray color of the rock. In the darkest portions of the rock may be seen, along with pyrite, a black opacite which shows no definite forms, and may be carbonaceous. Fig. 2 on plate VIII is drawn so as to exhibit these irregular transparent grains, as they appear in ordinary light, distributed throughout the section made from rock 1565, the siliceous grains of the jaspilyte, which made up the rest of the section, being disregarded.

Plate IX represents the appearance of rock 1571 in thin section. The upper portion (Fig. 1) shows its appearance in ordinary light, the green and darker green being chlorite scabs and fibers, and the uncolored part being quartz. In respect to the chlorite it may be seen easily that it is derived from original hornblende grains, since in many instances there are remnants of hornblende still visible with its characteristic cleavages and polarization, one mineral showing a relation of transitional dependence on the other.

The lower portion of Fig. 2 represents the same surface when placed between crossed nicols and under the Klein quartz plate. It is at once apparent that throughout the siliceous portion are numerous silica grains of larger size and more brilliant polarization than are usual in the sections of pure chalcedonic silica, although still the larger portion of the silica cannot be distinguished from that characteristic of the jaspilyte. This greater coarseness shows that this greenish belt, embraced within the characteristic jaspilyte, was accumulated during a short interval of greater agitation, and one not favorable for the gentler deposition of the chemical precipitate.

Rock 511 A (H).—This rock furnishes a remarkable instance of the contact of utterly dissimilar masses. The hand-specimen is, in part, composed of parallel layers of ferruginous silica and magnetite, followed by a soft ottrelite-schist of dark green color. The section is cut so as to include both formations and to show the line of contact, which is clear and sharp, without a trace of gradual transition. The silica of the ferruginous layers differs in no way from that of the jaspilyte, described under 867; we notice the same granular structure, the same polarization phenomena, the same absence of fluid-enclosures and the same prevalence of hex-

agonal forms. In some places, however, the layer is traversed by veins of crystallized quartz, intersecting the jaspilyte almost at right angles to the plane of bedding. These veins doubtless represent cracks and fissures, once existing in the stratum, which were filled with silica derived from a more recent source. The "vein-silica" contains numerous fluid-lacunae, and has a distinctly crystalline structure.

If we examine the ottrelite-schist we find it to be almost exclusively composed of minute yellowish-green and bluish scales, which exhibit an intense pleochroism if tested with the polarizer only. That these scales are neither hornblende nor epidote is manifested by their softness, and of all the minerals of the chlorite group ottrelite alone is characterized by such strong dichroism. It cannot, for a moment, be doubted that this green schist was deposited under conditions totally different from those which prevailed during the formation of the jaspilyte, but what these conditions were and whether the two formations were separated by considerable intervals of time must remain a matter of speculation.

Rock 866.—A heavy, dark red, or reddish-brown variety of ferruginous jaspilyte, interstratified with thin layers of magnetite, associated with hematite. Under the microscope the jaspilitic groundmass is found to be completely permeated, and almost obscured by dust-like grains of magnetite, as well as by larger crystals and aggregates of the same opaque mineral. In such portions of the field, however, as are sufficiently translucent the phenomena described under 867 and 511 A (*H*) may be observed without difficulty, viz: crypto-crystalline structure, hexagonal outlines and circular polarization. As these, in the writer's opinion, are indicative of a chemical origin (as set forth in the description of 867) it must be presumed that the iron oxides, now present as magnetite and hematite in the rock under consideration, were contemporaneously precipitated. When we were dealing with bands of almost pure jaspilyte, alternating with layers of iron oxide (as in 867) we were justified in inferring a slow and gradual deposition during periods comparatively free from disturbance, when the silica and iron, dissolved in the water, could be eliminated in the order of their respective gravities. It is clear, however, that jaspilyte, so intimately associated with hematite and magnetite, as in 866, could not have been precipitated before or after the iron oxides, and a contemporaneous accumulation of such dissimilar deposits would imply the action of disturbing forces. Whatever may have been the nature of these forces, one thing is certain, viz: that their operation was confined to limited areas, as

we find strata of almost pure jaspilyte alternating with hematite in close proximity.

Mixed chalcedonic silica and green schist. It was shown, under the head of *Structural features of the Keewatin hematites*, that generally the jaspilyte is distinct from the green rock in which it is embraced, but that on close inspection the minute fine grains of silica, evidently of the same origin, are disseminated among the schists (see also the microscopic description of rock 1557), more widely than had been supposed. It was also shown by plate II, which is a reproduced photograph of a jaspilyte surface, and by figure 7, p. 36, 18th annual report, that the element of the green schist is occasionally seen mingled with those beds which are, in general, distinctly composed of characteristic jaspilyte. One of these greenish jaspilyte layers afforded rock sample 1571. The inferences that spring from this association of these elements in the same layer are patent; (1) that the two substances, the green schist and the siliceous jaspilyte and the hematite, in their physical relations, are the product of practically identical forces, or the same force, acting on different objects; (2) that after the formation of some of the narrow bands they were disrupted and contorted before the formation of the next succeeding bands; and (3) that there was usually a complete cessation of the deposition of the siliceous jaspilyte when the materials of the green schist were accumulating, and *vice versa*, but that occasionally, as illustrated in these greenish jaspilitic layers, the two substances were deposited simultaneously.

Any theory that will satisfactorily account for the origin of the Keewatin ores must allow for these inferences from the structure, and from this microscopic association, at the same time that it plausibly accounts for the origination of the elements of which the jaspilyte and the green schist consist.

The section described below has a general greenish tint. Macroscopically, when fresh, and freshly broken, the rock appears like a fine dense diabase, the fine silica grains not being apparent to the eye. It was described by Dr. Hensoldt without his knowing the physical relations which the rock from which it came, bore to the stratigraphy of the region.

Rock 1571.—Plate IX., quartziferous chlorite-schist. This is a fine-grained, dark greenish-gray rock, composed of chlorite, biotite, magnetite and quartz. The chlorite predominates and appears to be very evenly distributed in the different layers, which, however present various degrees of comminution. Most of the chlorite occurs in irregular patches, composed of minute scales or fibres, but

FIG. 1

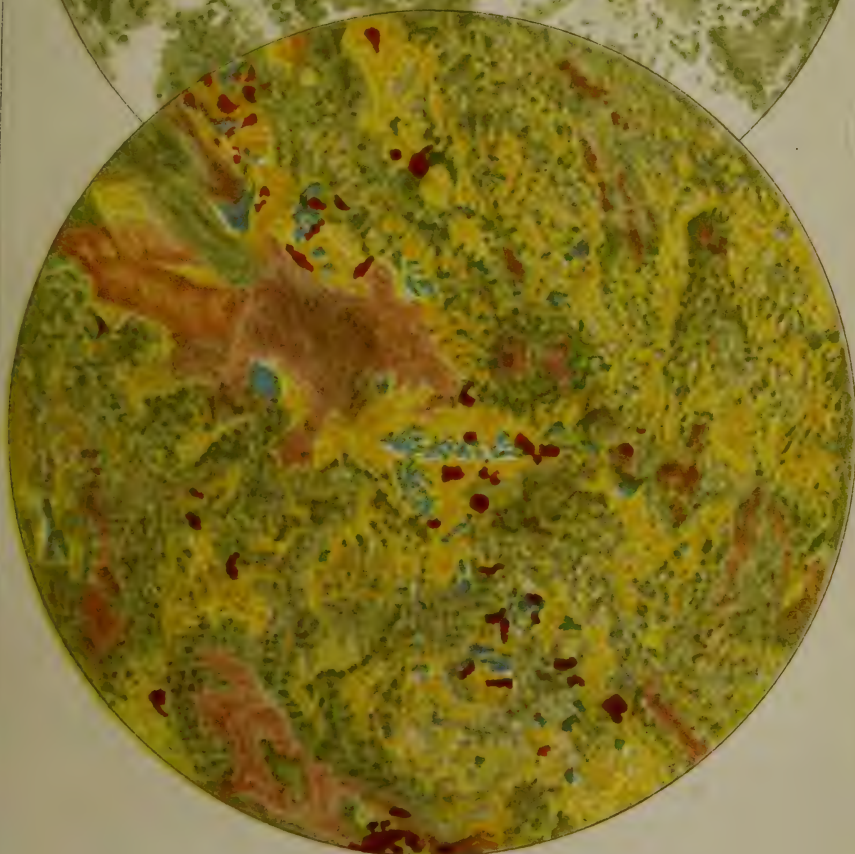
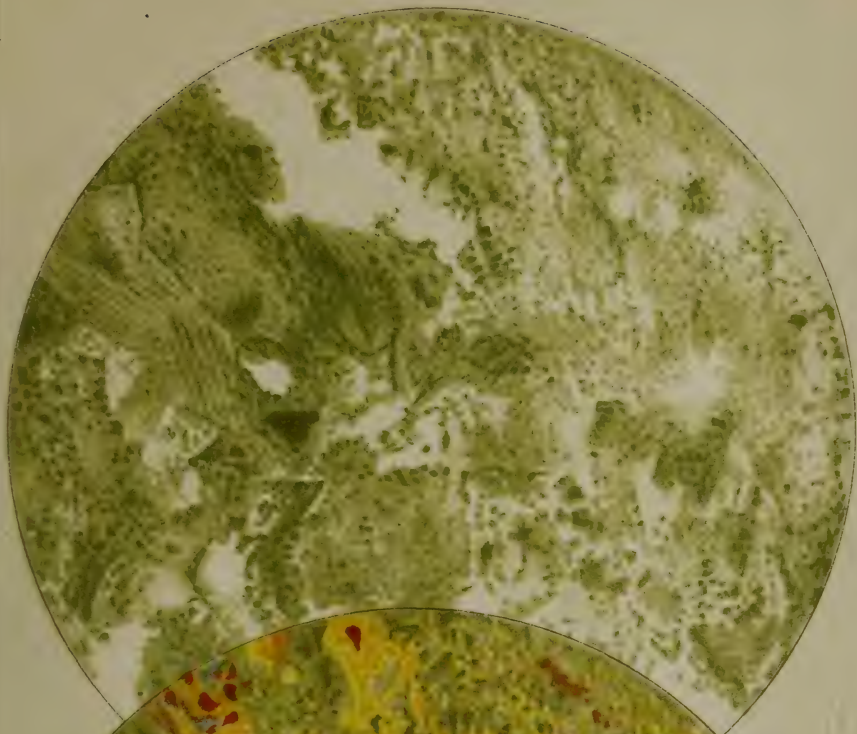


FIG. 2.

Section 127 - 20

granular masses, of an apparently homogeneous character, are likewise abundant. There are grounds for believing that this chlorite has resulted from a decomposition of biotite, as most of the granular masses show a distinct pleochroism, and we also observe biotite scales in all stages of alteration. But it is not improbable that the rock was originally a hornblende-schist, which became first transformed into a biotite and ultimately a chlorite-schist. The magnetite, as usual, occurs in rounded grains, irregular aggregates and crystals, which rarely present symmetrical outlines, but innumerable dust-like particles are also visible in almost every part of the field. The interstitial quartz is neither crystallized nor amorphous, but presents the same curious features which we have described, in full, under 867. It is pellucid, and devoid of fluid-lacunæ, and if we carefully examine one of the colorless patches, we find it to be an aggregate of minute granules which simulate hexagonal crystals and show circular polarization.

(4) *Quality of the Keewatin hematites.* Physically the Keewatin hematites are hard, and they require to be blasted. That is their usual condition; at Ely, however, in the Chandler mine, while the ore itself is hard, it is in fragments and can be mined with much less blasting. Indeed, in some cases it is excavated and hoisted without any blasting. This fragmentary condition seems to be due to a former brecciation recemented by siderite, from which the siderite has subsequently been removed. This is accordant with the fact that in the neighborhood of Ely have been discovered apparently large deposits of limonite, the probable product of such removal of siderite.

Chemically the Keewatin hematites manifest certain characteristic peculiarities by which they differ from all ores of later date, and by which they can be distinguished from the ores of the Taconic age. The elaborate methods of testing and assay of the ores practiced by the owners of the mines, are given in another part of this bulletin.* It is apparent that such thorough chemical examination affords the best possible opportunity to become acquainted with the qualities of the ore. These examinations are duplicated, in nearly all cases, by the purchasers, or by the selling agents, or by the furnace men who use the ores. Such averages are published in the grade lists of the principal dealers, and they give permanent reputation to the ores produced in all the mining districts of the country. A comparison of the Keewatin ores of Minnesota with those of the Taconic (Huronian) of the south side of lake Superior, based on an examination of several thousand assays, in

*See under *Methods of sampling and analyzing.*

1888, as published by Pickands, Mather and Co., shows that while the amount of silica and of phosphorus does not differ very much from that in the Taconic (Huronian) ores, in respect of other impurities there is a very important contrast. The latter ores contain about 300 per cent. more manganese, about 400 per cent. more sulphur, about 33 per cent. more alumina, about 25 per cent. less of magnesia, about 400 per cent. more lime, and about 400 per cent. more water.* It is not certain from what age of rocks some of these more southern ores came. Indeed, it is not certain, as yet, what mines of the Marquette iron range, or of the Menominee iron range, are in the rocks of Keewatin age. The writers are satisfied that some of the Marquette mines (particularly the Jackson mine) are in the Keewatin, and that others (particularly the Buffalo, the Queen, and others near them) are in the Taconic (Huronian). They also are inclined to place all the Penokee-Gogebic iron range in the Taconic (Huronian). Indeed, it is quite likely that the larger number of the south-shore mines are in the later formation. This judgment is based on an examination of the field relations of the strata, and was formed some years ago. It is a fact confirmatory of the correctness of this conclusion, that the average analysis of the ores from the south-shore mines indicates a considerable difference from that of the Vermilion ores of Minnesota—that, too, when the possible Keewatin ores of the south-shore mines cannot be separated accurately in the calculation, from those of Taconic age.

This contrast should be further examined, for it has a bearing on theories for the origin of the respective ores. It is probable that no chemist will question the statement that the presence of a larger percentage of lime, manganese, sulphur and water in the Taconic ores is an indication of their greater amenability, in the process of accumulation, to the ordinary methods of subaërial sedimentary, fragmental deposition, with the possible presence of organic matter. In other words, the chemical characteristics of the Taconic ores, so far as they can be made to indicate the physical conditions that prevailed at the time of their origination, are in harmony with their stratigraphic features. That is, they require both fragmental deposition, and successive alternations in the strata, from sandstone to shale, from shale to sandstone, and then possibly to limestone—or a mingling of all these principal ingredients in the same stratum. This will give the ores certain definite relations to the enclosing strata, and the mines may have char-

*On a possible chemical origin of the iron ores of the Keewatin in Minnesota. *American Geologist*. Vol. IV., p. 293.

acteristic hanging and foot walls, such as the Gogebic mines are known to possess.

On the other hand the presence of a greater amount of magnesia in the Keewatin ores indicates a sympathetic alliance with the characters of the enclosing green schists. Those schists, as will be further explained under the head "origin of the Keewatin hematites," are primarily derived from basic volcanic ejecta. They are not the product of ordinary fragmental accumulation under the abrasion and transport of oceanic waters. They were rapidly deposited, so rapidly that they acquired very great thickness. Under such conditions organic matter would be entirely excluded from the gathering sediments. There would be but scant opportunity for the formation of carbonates, for the deposition of lime, for the retention of sulphur in the sedimentary products, or for the slow evaporation that usually marks the gathering of manganese. If iron was accumulated then, by any method, it would be expected to partake of the prevailing characters of the enclosing strata. What more natural than that it should show a comparatively large percentage of magnesia, which is the chief alkaline base of the green schists. The Keewatin iron therefore not only has a chemical alliance with the green schist, but structurally this alliance, through the chemical reactions that took place in the agitated Keewatin ocean, is made still stronger by reason of the co-relations which they manifest, such that only chemical forces could have established. As it is intended here, however, to mention simply the distinguishing qualities of the Keewatin hematites, a discussion of these relations is deferred to a later chapter.

EXCELLENCE OF THE KEEWATIN ORES.

To conclude this sketch of the quality of the Keewatin ores from Minnesota, attention will be called to the comparative grade of excellence which they maintain. This grade is not to be established by selecting individual analyses, nor by the analyses, however numerous, of parties who might be supposed to have some interest in their high standing. As has already been stated, the recognized grades of the iron ores of the country are established by repeated assays, beginning with mine owners, then going to the shipping officers, thence to the agents or sellers, then to the purchasers, and lastly the users. Thus all the ores are put to a very thorough test. The average results of these assays, sometimes amounting, during a single season, to several thousand tests, are taken as the grade-standing of the respective ores.

An extensive comparison of the published grades of the princi-

pal ores of iron has demonstrated that THE KEEWATIN ORES OF MINNESOTA, AS PRODUCED FROM THE MINES AT TOWER AND ELY, ARE PURER THAN ANY IRON ORES MINED TO ANY EXTENT IN THE WORLD.

This statement is based on the analyses published by James M. Swank,* the United States census (10th), William P. Blake.† and by Pickands, Mather & Company, of Cleveland. Those analyses that show the quality of the Lake Superior ores, published by Mr. Swank, are as follows :

THE MARQUETTE RANGE.

AVERAGE QUALITY OF THE ORE OF THE REPUBLIC MINE, MARQUETTE, MICH.—Shown by fourteen analyses. From A. P. Swinefords's "Mineral Resources of lake Superior." [After Swank.]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	Av.
Metallic iron ..	65.11	67.75	68.01	69.88	69.24	71.82	68.40	68.23	65.86	69.89	67.55	68.00	68.40	70.60	68.48
Phosphorus	tree	.05	tree	.018	.....	.....	.08	.15	.073	.06	.045	.05	.....	.....	.053
Silica .....	.....	.....	.....	.....	1.08	.84	.86	3.53	4.63	2.02	2.3	.....	.....	1.10	2.07
Lime .....	.....	.....	.....	.....	.....	.....	.82	.....	.....	.....	.....	.....	.....	.....	.....
Magnesia .....	.....	.....	.....	.....	.....	.....	.33	.....	.....	.....	.....	.....	.....	.....	.....

"The iron ore of the CHAMPION MINE shows 67 per cent. of iron, 3 per cent. of silica, and .03 per cent. of phosphorus. Several analyses of WEST REPUBLIC ore that are before us show iron ranging from 66.483 to 68.583 per cent., and phosphorus ranging from .039 to .054 per cent. Two analyses of the specular ore of the LAKE SUPERIOR MINE give the following results:"

Metallic iron	64.831	65.680
Silica	3.600	3.700
Alumina	2.030	2.370
Lime .....	.550	.700
Magnesia .....	.600	.350
Phosphorus .....	.067	.095

MENOMINEE RANGE.

	Vulcan.	Cyclops.	Norway.	Quinnesec.
Iron	63.930	60.470	58.940	67.05
Silica	6.860	3.380	12.270	4.80
Phosphorus .....	.013	.009	.016	.01

* A bird's eye view of the production and characteristics of the iron ores in the United States, 1885. (In mineral resources of the United States, Williams, for 1883-4.)

† Report on iron and steel, Vienna International exhibition, 1873.

THE GOGEBIC RANGE.

COLBY MINE.

	1.	2.	3.	4.	5.
Iron and manganese....	60.040	62.340	62.760	66.020	61.270
Metallic iron.....	48.630	55.490	57.140	65.100	52.700
Phosphorus.....	.083	.070	.071	.042	.075
Silica	6.080	2.680	3.690	8.840	1.820
Manganese.....	11.410	6.850	5.620	.920	8.570

"Most of the analyses of the iron ores of this district that have been made show metallic iron ranging from 50 to 66 per cent."

IRON MOUNTAIN, MISSOURI.

The following analyses were published by Mr. W. B. Potter, in 1884, in the *Journal of the United States Association of Charcoal Iron-workers* [after Swank:]

	Surface ore.	Bluff ore.
Peroxide of iron.....	95.040	90.610
Protoxide of iron.....	2.570	2.800
Silica.....	1.570	3.750
Alumina.....	.790	2.160
Lime.....	.170	.480
Magnesia.....	.140	.320
Manganese.....	none	trace
Sulphur.....	.005	trace
Phosphoric acid.....	.071	.075
	100.356	100.195
Metallic iron.....	68.530	65.610
Phosphorus.....	.031	.033

"A statement which we have received from the Iron Mountain Company gives the average analysis of a series of samples of No. 1 ore from Iron Mountain as follows :"

Metallic iron.....	65.5000
Silica.....	5.7500
Sulphur.....	.0160
Phosphorus.....	.0405

PILOT KNOB, MISSOURI.

Peroxide of iron.....	84.330	90.870
Protoxide of iron.....	0.150	1.670
Silica.....	13.270	5.180
Alumina.....	2.190	.890
Lime.....	.210	1.760
Magnesia.....	.140	.130
Manganese.....	none	none
Sulphur.....	trace	.078
Phosphoric acid.....	.035	.069
	100.325	100.647
Metallic iron.....	59.150	64.9100
Phosphorus.....	.015	.0031

SIMMONS MOUNTAIN, MISSOURI.

Peroxide of iron.....	98.140
Silicic acid.....	1.410
Alumina.....	.060
Lime.....	.240
Magnesia.....	.110
Phosphoric acid.....	.038
	99.998
Metallic iron.....	68.690
Phosphorus.....	.016

CORNWALL ORE DEPOSIT, LEBANON CO., PENNSYLVANIA.

Results of "six samples selected to give a general average of the quality of the ore."—[Swank.]

	No 1.	No 2.	No 3.	No 4.	No 5.	No 6.
Magnetic oxide of iron.....	78.278	62.198	67.282	68.965	53.075	41.131
Sesquioxide of iron.....			trace	22.794		52.298
Oxide of copper.....	1.840	1.480	trace	0.250	1.300	0.030
Oxide of cobalt.....	0.200	0.095	0.153	0.067	0.076	0.105
Oxide of manganese.....	trace	trace	trace	trace	trace	trace
Magnesia.....	1.286	2.695	1.867	1.228	3.193	1.369
Lime.....	1.000	1.110	1.210	1.403	1.510	1.111
Sulphuric acid.....	0.039	0.204	0.105	0.013	0.187	
Phosphoric acid.....	0.072	0.010	0.006	0.002	0.003	0.006
Quartz and silica.....	11.082	28.000	18.240	2.200	37.860	3.840
Copper pyrites.....	0.352	1.818	0.232	0.084	0.604	
Iron pyrites.....	5.222	1.792	8.299		1.479	
Water, etc.....	0.629	0.598	2.522	2.943	0.603	2.107
	100.000	100.000	100.000	100.000	100.000	100.000
Metallic iron.....	59.229	46.422	52.666	65.952	39.380	64.992
Metallic copper.....	1.589	1.814	0.080	0.2 0	1.246	0.024
Phosphorus.....	0.032	0.004	0.002	0.007	0.001	0.002
Sulphur.....	2.910	1.672	4.549	0.045	1.076	

SALISBURY, CONNECTICUT.

	Davis.	Chatfield.	Old Hill.
Sesquioxide of iron.....	75.720	78.136	73.51
Sesquioxide of manganese.....	1.376	.826	.96
Silica.....	7.580	6.630	10.48
Sulphur.....	.082	.048	.07
Phosphoric acid.....	.032	.501	.57
Lime, magnesia, alumina, water, etc.....	15.210	13.857	14.41
	100.000	99.998	100.00
Metallic iron.....	53.000	54.696	51.45
Metallic manganese.....	.958	.576	.67
Sulphur.....	.082	.048	.07
Phosphorus.....	.014	.219	.25

"The pig iron produced from the Salisbury iron ores is in high repute for the manufacture of car-wheels and of rolls for rolling mills, but it is also in demand for all purposes requiring great strength and tenacity. More than a century ago there were many forges in this district which produced bar iron of superior quality. The American navy has been supplied with many guns made from Salisbury iron. Only the ore of the Davis mine appears to be adapted to the manufacture of steel."—[Swank.]

PORT HENRY, NEW YORK.

SEVEN ANALYSES.

	1.	2.	3.	4.	5.	6.	7.
Magnetic oxide of iron.....	88.323	88.772	76.608	81.381	85.559	84.623	92.78
Phosphoric acid.....	1.791	1.513	4.227	4.694	3.297	3.495	.71
Equivalent to—							
Metallic iron.....	63.958	64.287	55.475	58.935	61.957	61.279	67.19
Phosphorus.....	.782	.661	1.846	2.050	1.440	1.528	.31

"The quality of the iron made in this whole region is most excellent, and it enjoys a high reputation for various uses. As a rule the iron ores of this district are not adapted to the manufacture of any kind of steel, but some Bessemer pig iron is made in the district, and some mines produce ores the blooms and billets from which have been used in the manufacture of crucible steel."

Prof. W. P. Blake has given four analyses of ore from the "Arendal vein," Essex county, N. Y., in the report on the Vienna International exhibit,* showing a range of metallic iron from 54 to 58 per cent as follows:

Magnetic oxide of iron.....	79.29	80.91	75.01	79.83
Oxide of manganese.....	0.35	0.42	0.42	0.72
Alumina.....	3.45			
Lime.....	4.46			
Magnesia.....	3.09			
Sulphur.....	3.35	0.08	0.08	0.41
Phosphoric acid.....	0.32	0.03	0.03	trace
Silicic acid.....	8.32	8.77	13.34	8.55
Water.....	0.51			
Equivalent to.....	100.14			
Metallic iron.....	57.42	58.59	54.32	57.81
Metallic manganese.....	0.23	0.29	0.29	0.50
Phosphorus.....	0.14	0.01	0.01	trace
Sulphur.....	0.35	0.08	0.08	0.41

STERLING MINES, ORANGE COUNTY, N. Y.

	Cook mine.	Scott mine.
Iron.....	64.24	65.47
Oxygen.....	24.48	24.93
Silica.....	7.45	4.92
Sulphur.....	none.	none.
Phosphorus.....	.184	.52
Alumina.....	1.13	.71
Lime.....	.72	1.59
Magnesia.....	.29	.56
Oxide of manganese.....	.17	.32
	98.664	99.02

TILLY FOSTER MINE, PUTNAM COUNTY, N. Y.

Magnetic oxide of iron.....	67.41	Sulphur.....	.08
Oxide of manganese.....	.30	Carbonic acid.....	2.30
Silica.....	11.75	Phosphoric acid.....	.05
Alumina.....	3.50		
Lime.....	2.15		100.78
Magnesia.....	13.24	Metallic iron.....	48.82

*Iron and Steel, p. 237.

NEW JERSEY ORES.

Magnetic Ores From Sussex County.

	Hill vein.	Furnace v'n.
Magnetic oxide of iron.....	69.50	65.40
Oxide of manganese.....	.46	4.13
Silica.....	18.27	1.05
Alumina.....	.27	.18
Lime.....	5.00	9.74
Magnesia.....	2.73	6.44
Sulphur.....	.10	.45
Carbonic acid.....	3.55	11.93
Phosphoric acid.....	.03	.05
Graphite.....		.78
	99.91	100.15
Metallic iron.....	50.32	47.35

"A larger general average of New Jersey magnetic ores would show a higher percentage of metallic iron and would be more favorable in other proportions for special purposes. For example, the ore of the Richard mine, in Morris county, owned and operated by the Thomas Iron Company, averages 60 per cent. of metallic iron, and contains some phosphorus but no sulphur."

CRANBERRY ORE, NORTH CAROLINA.

	1.	2.	3.	4.	5.
Magnetic oxide of iron.....	94.37	91.45	85.59	80.77	91.89
Oxide of manganese.....	.26	.06	.24	1.42	.32
Alumina.....	.42	.77	.11	.52	1.03
Lime.....	.43	1.01	.72	.....	1.06
Magnesia.....	.36	.53	.33	.....	.23
Water.....	.....	.44	1.53	8.21	1.15
Silica, pyroxene, etc.....	4.16	5.74	11.48	9.08	4.02
Sulphur.....	.....	.....	.....	.....	.25
Phosphoric acid.....	.....	.....	.....	.....	trace
	100.00	100.00	100.00	100.00	99.95
Metallic Iron.....	68.34	66.22	61.98	58.49	66.53

"North Carolina has many other deposits of magnetic and hematite ores, which have been fitfully worked in a small way for more than a century, but none of these deposits, not even the Cranberry "ore bank," will compare in extent with the immense deposits of lake Superior, the Iron Mountain and Pilot Knob in Missouri, and the Cornwall "ore hills" in Pennsylvania. The coal deposits in North Carolina are as yet practically undeveloped."

ALABAMA, TENNESSEE, KENTUCKY.

The following analyses will show the general quality of the southern iron ores. These states do not as yet produce any ap-

preciable quantity of steel. Very small quantities of ore suitable for the manufacture of Bessemer steel have been discovered.

ALABAMA ORE.

	Magnetite	Red Hematite.		
		1.	2.	3.
Oxide of iron	66.05	63.87	84.58	80.64
Oxide of manganese	10.25	.23	.40	.40
Alumina	6.98	.29	3.14	.50
Lime .....		.18	5.06	.12
Magnesia .....		.43	1.23	.33
Silica	13.00	33.22	5.54	16.80
Phosphoric acid	1.08	1.16	.07	.88
	97.36	99.38	100.02	99.67
Metallic iron	47.83	44.71	61.240	56.45
Phosphorus .....	.147	.50	.030	.34

KENTUCKY ORE.

Peroxide of iron	76.070	Water	12.310
Alumina	2.590		
Lime .....	.130		100.561
Magnesia .....	.281	Metallic iron	48.00
Silica	8.180	Manganese .....	.48
Phosphoric acid	1.000	Phosphorus .....	.70

In general the "fossil" ores of the southern states range from 39 to 56 per cent. of metallic iron, and are too high in phosphorus for the manufacture of Bessemer steel.*

TENNESSEE ORE.

Mr. P. N. Moore gives the following analysis of Tennessee ores. They were made by Dr. Peter and Mr. Talbutt, from samples collected by Mr. Moore. No. 1 is the upper or soft ore from the valley near the Virginia road a short distance above Cumberland Gap. No. 2 is the same ore from the ridge below Cumberland Gap. No. 3 is the middle or hard ore from the ridge near the same place as No. 2.†

	1.	2.	3.
Iron peroxide	73.935	77.880	47.965
Alumina	5.776	3.941	2.130
Lime carbonate	4.510	.420	1.230
Magnesia .....	.266		.194
Phosphoric acid .....	.319	.319	.575
Sulphuric acid			trace.
Silica and insoluble silicates	11.730	15.960	43.690
Combined Water	3.850	2.500	4.000
Total	100.386	100.520	99.784
Metallic iron	51.754	54.166	33.575
Phosphorus .....	.140	.140	.251
Specific gravity	3.914	3.942	3.190

*A. S. McCreath, Trans. Am. Inst. Min. Engineers, Feb. 1887.

†Geological survey of Kentucky. Report of the iron ores of the vicinity of Cumberland Gap, Part V, Vol. IV, Second Series, p. 252.

GREAT BRITAIN.

The iron ores of Great Britain are found in the Carboniferous limestone, the Coal Measures and in the Lias.* As a class they are very different, geologically and structurally, as well as chemically, from those of Minnesota. They are clay ironstones, and black band ores, with some red hematites. Their percentage of metallic iron ranges from 28 to 66 per cent. They have a variety of impurities, such that they are generally not suited to the manufacture of Bessemer steel. The most important hematite mines in England are those of Ulverstone in Lancashire, and Whitehaven, in Cumberland (Bauerman), which occur in very irregular deposits in the Carboniferous limestone. The following analyses of these ores are given by Bauerman (Treatise on the Metallurgy of Iron, 1872, p. 68).

	1	2	3	
Peroxide of iron.....	90.36	95.16	94.23	
Protoxide of manganese.....	0.10	0.24	0.23	
Alumina.....	0.37	.....	0.51	
Lime.....	0.71	0.07	0.05	
Magnesia.....	0.06	.....	.....
Phosphoric acid.....	.....	.....	0.09	Sulphuric acid.
Bisulphide of iron.....	0.06	.....	0.03	
Insoluble residue.....	8.54	5.68	5.18	
Total.....	100.20	101.15	100.32	
Metallic iron.....	63.25	66.60	65.96	

The same authority gives the following analysis of steel-making Bessemer ores employed at Barrow-in-Furness iron works, Lancashire. No. 1 is Park ore (best rough), No. 2 is Lindal cote (puddling), No. 3 is Whitrigg's (puddling), and No 4 is from the Mouzell mine (best).

	1	2	3	4
Peroxide of iron.....	94.88	77.24	83.33	83.94
Alumina.....	0.07	1.71	0.75	0.70
Protoxide of manganese.....	0.04	0.11	0.08	0.28
Lime.....	0.34	6.08	4.10	0.85
Magnesia.....	trace	0.41	0.15	0.09
Water.....	0.47	2.82	1.97	2.28
Phosphoric acid.....	0.03	.....	.....	0.03
Sulphuric acid.....	.....	.....	trace	.....
Carbonic acid.....	.....	4.19	2.53	.....
Silica.....	4.55	7.36	6.59	12.46
Total.....	100.38	99.92	99.50	100.63
Metallic iron.....	66.	54.07	58.33	58.76

*Percy. Memoirs of the Geological Survey of Great Britain. The iron ores of Great Britain, Part I.

SCANDINAVIA.

Of all the foreign ores those of Scandinavia approach nearest to the excellence, and the geological age, of the hematites of Minnesota, and of the Scandinavian ores those from the provinces of Upsala and Kopparberg are the most noted. The following table is made by taking the average of the ten analyses given by Mr. W. P. Blake in his "Report on Iron and Steel," Vienna exposition, of ores from the parishes of Films, Dannemora, Alunda and Lena, and the same of the first forty-three analyses given from the province of Kopparberg. These analyses were made by Swedish chemists, and give results probably above that which would be got by the regular method of average analysis by iron dealers.

	Average of 10 analyses from Upsala.	Average of 43 analyses from Kopparberg.
Magnetic oxide of iron.....	78.64	*73.23
Protoxide of manganese.....	1.31	.80
Phosphorus.....	.009	.113
Sulphur.....	.036	.021
Metallic iron.....	56.91	51.18

"The amount of iron in the Swedish ores varies from 30 to 70 per cent. It is, however, usually about 45 or 50 per cent.
* * * The 'mine ores' contain usually very little phosphorus, and among those most free from phosphorus are the ores from Dannemora, in Upsala, with 0.003 per cent of phosphorus, and from Persberg in Wermland with 0.004 to 0.005 per cent. of phosphorus. Usually the amount of phosphorus varies between 0.005 and 0.05 per cent., although there are some with a tenth of one per cent" (Blake).

SPAIN.

Large quantities of Spanish ore have formerly been introduced in the United States. They are from the left bank of the river Nervion, above the town of Bilbao, province of Biscay, associated with rocks of Cretaceous age. They are red and brown hematites, principally the latter, and have the following chemical qualities, according to Mr. J. Arthur Phillips. †

* In making the average the protoxide and the sesquioxide are not reckoned separately.

† A treatise on ore deposits, p. 378, 1884.

	Red ore.	Red ore.	Brown ore.
Ferric oxide.....	78.03	79.96	78.29
Alumina.....	.21	1.44	1.15
Manganous oxide.....	.86	.70	.74
Lime.....	3.61	1.00	.50
Magnesia.....	1.65	.55	.02
Silica.....	5.91	8.10	8.80
Sulphuric acid.....	.01	.10	.65
Sulphur.....	trace	.05	.04
Phosphoric acid.....	.03	.03	.02
Carbonic acid.....	5.00	.....	.....
Combined water.....	4.60	8.25	10.55
	99.91	100.18	100.16
Metallic iron.....	54.62	55.97	54.80

CUBA.

According to Mr. J. P. Kimball (Am. Jour. Sci. Vol. xxviii, Dec. 1884., p. 426) the iron ores of the Juragua hills, province of Santiago, Cuba, have the following chemical character, based on numerous average proximate analyses from commercial samplings: Moisture, 0.24 to 0.81; silica and insoluble, 5. to 10.5; phosphorus, 0.009 to 0.065; sulphur, 0.045 to 0.248; and iron 61. to 68.5.

OTHER COUNTRIES.

The principal iron ores of France are of Jurassic age. Those of Belgium are, like those of England, of Carboniferous or Permian age. The German iron ores are Devonian in part and in part Carboniferous. Some are also Jurassic, and some are associated with masses of greenstone penetrating the Silurian rocks. The Russian magnetites are from porphyry rocks on the east side of the Ural chain. Other ores are in the Urals, forming lodes and bedded masses in hornblendic rocks and in crystalline schists. In the western Urals are found Carboniferous rocks carrying carbonates and brown hematites. Of these Russian ores none but the eastern magnetites can be supposed to approach the high grade shown by the Minnesota hematites.

THE MINNESOTA HEMATITES.

Chemical Analyses.

Numerous analyses of the Vermilion ores are published in the thirteenth annual report. Others are given in the fifteenth and sixteenth reports. The following lists have more recently been copied by us from the records of the assay laboratory at Tower.

ANALYSES.—Continued.

Date.	Metallic iron.	Phos- phorus.	Silica.	Alumina.	Lime.	Magnesia.	Sulphur.	Manganese.	Remarks.
Feb. 18, '87	68.37	.057	1.10	0.50	none	0.014	.007	Loss by ignition 0.56	Stone mine, No. 2 stope.
Feb. 25, '87	68.51	.028	1.13	.....	.....	.....	.....	.....	Stone mine, 2d shaft, face of drifts.
March 12, '87	68.52	.046	1.35	0.25	none	none	none	Loss by ignition 0.66	Stone mine, upper stope.
March 19, '87	67.37	.021	1.35	.....	.....	.....	.....	.....	Stone mine, No. 2 shaft from two drifts
June 28, '87	68.22	.086	0.82	0.93	none	0.18	none	Loss by ignition 0.62	Tower mine, No. 2 pit, current mining
Sept. 17, '87	67.87	.050	1.30	0.10	0.36	0.07	none	(No min) 0.50	Train sampled, 62 cars.

Analyses of samples from the diamond-drill cores and from other places at Tower.

Date.	Metallic Iron.	Phosphorus.	Silica.	Remarks.
April 26, 1888..	66.71	.090	2.02	Drill core from F. hole, 4 ft. vein.
April 26, 1888..	68.93	.130	0.58	Drill core from F. hole, 38 ft. vein.
April 23, 1888..	63.40	.086	4.25	Ely mine, No. 2 stock pile.
May 12, 1888..	67.16	.018	1.64	Stone mine, No. 2 stock pile.
May 23, 1888..	65.13	.020	.....	Sec. 26, 63-12, from Mr. Bacon.
June 11, 1888..	68.73	.123	.40	Drill core sample from 47 ft., 10 in. vein at E. Tower, 25th ft.
June 11, 1888..	68.51	.158	.50	Drill core sample from 47 ft., 10 in. vein at E. Tower, 46th ft.
June 11, 1888..	68.82	.186	.30	Drill core sample from 47 ft., 10 in. vein at E. Tower, 3d foot.
June 30, 1888..	60.42	.061	10.34	Stuntz mine, west stope.
June 30, 1888..	66.65	.081	2.72	Stuntz mine, east stope.
July 6, 1888..	68.42	.024	1.43	Tower mine, N. of No. 9 pit.
July 10, 1888..	56.95	.081	14.96	3 cars Breitung, No. 16, Red Lake.
Aug. 21, 1888..	59.00	.065	12.92	4 cars Breitung, No. 14 pocket, Red Lake.
Sept. 12, 1888..	67.70	.037	1.45	Montana, sampled.
Sept. 16, 1888..	55.87	.324	11.07	From a drift at Jasper Peak, sampled by Capt. Wallace.
Sept. 19, 1888..	69.30	.041	0.55	Montana.
Oct. 12, 1888..	58.40	.060	14.54	2 cars S. Lee pocket, Bess, Red Lake.
Oct. 18, 1888..	69.00	.034	0.81	Montana pit, Bessemer
Oct. 25, 1888..	68.96	.035	1.00	Montana pit, Bess.
Oct. 30, 1888..	63.18	.045	6.42	Diamond drill core. Hole at S. Lee hill.
Oct. 30, 1888..	68.40	.053	1.40	Diamond drill core. Hole T., 29 ft. vein at Stone, 10th foot.
Oct. 30, 1888..	67.85	.142	0.97	Diamond drill core. Hole T., 29 ft. vein at Stone, 19th foot.
Dec. 8, 1888..	63.85	.052	7.20	No. 1 pit; No. 1 stockpile.
Dec. 8, 1888..	67.90	.044	1.63	Nos. 3 and 4 pits; No. 1 stockpile.
Dec. 8, 1888..	67.50	.053	1.75	Ely pit; No. 1 stockpile.
Dec. 8, 1888..	68.38	.107	1.00	No. 8 pit; No. 1 stockpile.
Dec. 8, 1888..	66.40	.078	2.84	No. 8 pit; No. 2 stockpile.
Dec. 8, 1888..	63.50	.048	6.58	No. 3 pit; No. 2 stockpile.
Dec. 8, 1888..	64.90	.032	5.91	No. 9 pit; No. 1 stockpile.
Dec. 8, 1888..	60.30	.053	11.83	No. 9 pit; No. 2 stockpile.
Dec. 8, 1888..	65.11	.050	2.85	South Lee stockpile.
Dec. 8, 1888..	61.55	.147	9.22	North Lee stockpile.
Dec. 15, 1888..	65.70	.036	3.12	No. 11 pit; stockpile.
Dec. 15, 1888..	63.65	.132	6.01	No. 10 pit; stockpile.
Dec. 22, 1888..	68.20	.085	1.73	No. 6 pit; No. 1 stockpile.
Dec. 23, 1888..	66.80	.108	2.73	No. 17 pit; No. 1 stockpile.
Jan. 5, 1889..	61.81	.065	6.39	No. 19 pit; stockpile.
Jan. 23, 1889..	67.90	.098	1.44	Drill core Z. hole at Stone; 23 ft., 10 in. vein last 10 feet.
Jan. 23, 1889..	65.10	.076	5.93	Drill core, Z. hole at Stone; 23 ft. 10 in. vein first 8 feet.
Feb. 15, 1889..	69.15	.012	0.83	Drill core, Z. hole at No. 3, 3d to 19th foot.
Feb. 15, 1889..	69.25	.019	0.80	Drill core Z. hole at No. 3, 19-24 foot.
Feb. 15, 1889..	69.05	.060	1.20	Drill core Z. hole at No. 3, 3d foot.
Feb. 15, 1889..	68.95	.041	.64	Drill core Z. hole at No. 3, 37th foot.
Feb. 15, 1889..	63.00	.053	8.68	Drill core Z. hole at No. 3, 4 ft. 2 in. vein.
Feb. 15, 1889..	68.42	.037	1.15	Drill core Z. hole at No. 3, 24th-35th foot.
Feb. 15, 1889..	67.92	.055	1.56	Drill core Z. hole at No. 3, 35th foot.
Feb. 23, 1889..	68.75	.038	1.11	No. 5 pit; No. 1 stockpile.
Feb. 23, 1889..	62.10	.039	9.93	No. 5 pit; No. 2 stockpile.
Mar. 1, 1889..	58.60	.047	13.43	No. 5 pit; No. 2 stockpile.
Mar. 1, 1889..	68.92	.061	0.94	No. 5 pit; No. 1 stockpile.
Mar. 1, 1889..	68.62	.029	0.74	Drill core from Z. hole at No. 3, 623d ft. from surface.
Mar. 11, 1889..	68.57	.037	.88	39 cars Bess, from No. 3.
Mar. 14, 1889..	68.32	.088	1.31	B. hole at No. 3, 13 ft. vein, 127 ft. from surface.
April 12, 1889..	63.80	.152	6.02	B. hole at Stone, 4th ft. 350 ft. from surface.
April 12, 1889..	63.15	.150	7.86	B. hole, 8th ft., 382 ft. deep.
July 15, 1889..	68.95	.045	.41	HH. hole at Montana, 22 ft., 6 in. vein, 262 ft. from surface.
July 15, 1889..	69.50	.019	.25	HH. hole at Montana, 8 ft., 6 in. vein, 208 ft. from surface.
July 15, 1889..	69.55	.020	.32	HH. hole at Mon., 3 ft. vein, 198 ft. from surface
July 15, 1889..	67.75	.069	1.25	HH. hole at Mon., 1 ft. vein, 235 ft. from surface

By reference to plates VII and X the location of some of the

drill cores, above analyzed, can be seen, and their depth below the surface, together with their relations to the green schist.

Analyses of Keewatin hematite from N. W. $\frac{1}{4}$ Sec. 64, 2-14.

(By Prof. J. A. Dodge.)

	No. 1.	No. 2.
Silica	21.70	5.26
Lime	0.21	0.15
Phosphorus	0.17	0.18
Magnesia	trace	trace
Manganese	none	none
Titanium	none	none
Sulphur	none	none
Mag. oxide	77.62	92.76
	<hr/>	<hr/>
	99.70	98.35
Metallic iron	56.21	67.11

Samples from town 62-15 were analyzed in 1875 by Prof. A. H. Chester, one from sec. 27, giving 64.25 per cent metallic iron, one from sec. 28, giving 67.77, and one from sec. 33, giving 65.19. An average is given below of the analyses of all the samples obtained at that time by Prof. Chester.

From T. 62-15, secs. 28, 29 and 30. (Average result.)

(By A. H. Chester.)

Silica	7.57
Alumina	1.89
Phosphorus	trace
Sulphur	0.05
Oxygen with iron	27.11
Metallic iron	63.26
	<hr/>
Total	99.88

From Vermilion Lake. (Assorted samples in 1880.)

(By A. H. Chester, Clinton, N. Y.)

	No. 1.	No. 2.
Silica	3.39	3.89
Iron	66.93	66.43
Alumina	0.74	0.85
Lime	0.08	trace
Phosphorus	0.011	0.006
Sulphur	0.01	none
Oxygen	28.695	28.477
	<hr/>	<hr/>
	99.856	99.653

The *average quality* of the ores is, however, indicated most reliably by the advertised grades and guarantees of disinterested parties. Pickands, Mather and Company, Cleveland, O., who have handled the Minnesota ores, as agents for the Minnesota Iron Company, published the following average grades maintained in 1888, and the guarantees for grades for 1889.

"MINNESOTA" ORE.

"Bessemer hard red specular."

Average of the Analyses for 1888.		Guarantee for 1889.	
Fe.....	67.93	Fe.....	66.66
Si.....	1.97		
P.....	.054	P.....	.055
Mn.....	.15	NOTE.—For the months of April, May and June, 1889, the average of phosphorus in this grade was maintained at .046. No later information was obtained.]	
Al ₂ O ₃.....	.40		
S.....	.02		
Mg O.....	.14		
Ca O.....	.53		
H ₂ O.....	.50		

"BRADDOCK" ORE.

"Bessemer hard red specular."

	Average of Analyses for 1888.	Guarantee for 1889.
Fe	[This grade was not established until 1889.]	Fe..... 65.00
Si		
P		P..... .055
Mn.		[NOTE.—For the months of April, May and June, 1889, the average of phosphorus in this grade was maintained at .048, and no later information was obtained.]
Al ₂ O ₃		
S.		
Mg O		
Ca O		
H ₂ O		

"NIPIGON" ORE.

"Hard Red Specular."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....	63.88	62.00
Si.....	6.05	
P.....	.051	.055
Mn.....	.14	NOTE.—For April, May and June the average of phosphorus in this grade was .042
Al ₂ O ₃.....	.65	
S.....	trace	
Mg O.....	.20	
Ca O.....	.60	
H ₂ O.....	.50	

The "Minnesota," "Braddock" and "Nipigon" are called Bessemer ores. The "Vermilion," "Soudan" and "Red Lake" grades are non-Bessemer.

"VERMILION" ORE.

"Non-Bessemer Hard Red Specular."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....	67.17	66.66
Si.....	2.15	
P.....	.083	.09
Mn.....	.15	
Al ₂ O ₃.....	.35	
S.....	.02	
Mg O.....	.15	
Ca O.....	.58	
H ₂ O.....	.50	

"SOUDAN" ORE.

"Non-Bessemer Hard Red Specular."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....		65.00
Si.....		
P.....		.09

"RED LAKE" ORE.

"Non-Bessemer Hard Red Specular."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....	63.98	62.00
Si.....	5.80	
P.....	.079	.09
Mn.....	trace	
Al ₂ O ₃.....	.65	
S.....	trace	
Mg O.....	.20	
Ca O.....	.60	
H ₂ O.....	.50	

"CHANDLER" ORE. [From Ely.]

"Granulated Specular."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....	64.63	64.00
Si.....	4.30	
P.....	.048	.05
Mn.....	trace	
Al ₂ O ₃	2.25	
S.....	.04	
Mg O.....	.19	
Ca O.....	.25	
H ₂ O.....	5.00	

"LONG LAKE" ORE. [From Ely.]

"Granulated Specular."

	Average of analyses in 1888.	Guarantee for 1889.
Fe.....	61.69	61.00
Si.....	7.00	
P.....	.053	.055
Mn.....	.54	
Al ₂ O ₃	2.75	
S.....	.047	
Mg O.....	.19	
Ca O.....	.25	
H ₂ O.....	5.00	

"COLBY ORE." [From Bessemer, Mich.]

"Soft Hematite."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.....	58.15	62. { Fe. Mn.
Si.....	3.50	
P.....	.053	.06
Mn.....	4.23	
Al ₂ O ₃	1.50	
S.....	.05	
Mg O.....	.10	
Ca O.....	.11	
H ₂ O.....	7.50	

MILWAUKEE ORE. [From Wisconsin.]

"Soft Hematite."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.	61.90	61.00
Si.	4.32	
P. ....	.139
Mn. ....	.45
Al ₂ O ₃.....	.60
S. ....	.08
Mg O. ....	.90
Ca O.	1.10	
H ₂ O.	9.00	

NORTH CHAMPION ORE. [Michigan Ore.]

"Soft Hematite."

	Average of analyses for 1888.	Guarantee for 1889.
Fe.	56.54	56.00
Si.	5.22	
P. ....	.193
Mn. ....	.012
Al ₂ O ₃	4.35	
S. ....	.08
Mg O.	2.24	
Ca O.	1.64	
H ₂ O.	8.00	

The amount of each grade of ore mined and shipped between December 1, 1888, and August 1, 1889, from the Minnesota mine, at Tower, is as follows. All but 12,797 tons of this was shipped between April 22, 1889, and August 1, 1889.

Vermilion, tons.	Soudan, tons.	Red Lake, tons.	Minnesota, tons.	Braddock, tons.	Nipigon, tons.	Total, tons.
59,476	32,372	35,998	141,083	13,459	31,134	314,522

Average analyses of shipments by the Minnesota Iron Company, season of 1889. The Minnesota, Braddock and Nipigon grades are regarded by the mine owners as Bessemer ores, in rank according to the order named, and the rest as non-Bessemer.

MINNESOTA GRADE.

Total shipment in 1889, 227,492 tons.

Laboratory where the analyses were made.	Number of tons averaged by each.	Average percentage of iron.	Average percentage of phosphorus.
Minnesota Iron Company.....	13,000	67.60	.049
Two Harbors.....	227,492	67.59	.050
Illinois Steel Company.....	40,000	67.39	.057
Carnegie Bros.....	140,000	67.43	.051
Rattle & Nye.....	44,000	67.94	.050
Cremer.....	4,000	68.27	.050
Average.....		67.70	.051

BRADDOCK GRADE.

Total shipment in 1889, 15,647 tons.

Minnesota Iron Company.....	3,000	63.69	.053
Two Harbors.....	15,647	64.99	.052
Rattle & Nye.....	4,000	66.35	.046
Cremer.....	6,000	66.10	.053
Average.....		65.28	.051

NIPIGON GRADE.

Total shipment in 1889, 40,599 tons.

Minnesota Iron Company.....	4,000	62.99	.054
Two Harbors.....	40,599	63.29	.052
Illinois Steel Company.....	20,000	62.64	.055
Rattle & Nye.....	8,000	64.97	.053
Cremer.....	6,000	61.87	.056
Average.....		63.15	.054

VERMILION GRADE.

Total shipment in 1889, 101,551 tons.

Minnesota Iron Company.....	7,000	67.55	.119
Two Harbors.....	101,551	67.18	.090
Carnegie Bros.....	80,000	67.67	.091
Rattle & Nye.....	24,000	67.33	.100
Average.....		67.43	.100

SOUDAN GRADE.

Total shipment in 1889, 67,545 tons.

Minnesota Iron Company.....	8,000	65.36	.103
Two Harbors.....	67,545	65.49	.096
Illinois Steel Company.....	36,000	66.02	.108
Rattle & Nye.....	8,000	64.97	.053
Cremer.....	6,000	65.70	.120
Average.....		65.67	.105

RED LAKE GRADE.

Total shipment in 1889, 64,985 tons.

Minnesota Iron Company.....	5,000	62.23	.108
Two Harbors.....	64,985	63.41	.097
Illinois Steel Company.....	18,000	60.88	.099
Rattle & Nye.....	4,000	62.60	.088
Cremer.....	8,000	62.78	.095
Average.....		62.95	.097

PERCENTAGE OF EACH GRADE SHIPPED.

Minnesota.....	44.25	Vermilion.....	20.32
Braddock.....	2.90	Soudan.....	12.78
Nipigon.....	7.59	Red Lake.....	12.16

From this it appears that considerably more than one-half of the ore mined is low in phosphorus, and that nearly one-half of it contains over 65 per cent of metallic iron and less than six-hundredths of one per cent of phosphorus. The rest of the output is but slightly below the Bessemer grade of phosphorus, and its grades (Vermilion, Soudan and Red Lake), are guaranteed to run respectively not less than 66.66, 65.00 and 62.00 per cent in metallic iron. It is probable that individual mines in other countries can be found that would show an equally low percentage of phosphorus, and others that might run as high in metallic iron. But it is not likely that there is a mining plant in the world that can combine in its year's product, a guaranteed standard of excellence so high in both these respects, and enter into contracts to furnish of such ore 300,000 or 400,000 tons per year. We do not hesitate to claim, therefore, for the Minnesota ores and their annual output, in point of quality and quantity, the leadership of the world. The ores of Dannemora, in Sweden, approach nearest this standard. They excel in their low phosphorus, but their product in tons is insignificant in comparison with that of Minnesota.

(5). *Origin of the Keewatin Hematites.* Our attention was directed to this problem at the outset of this investigation, and it has been continually under consideration. No one who visits the iron mines, be he geologist or chemist, can fail to be impressed with the perplexities that surround this question. The whole environment, physical and chemical, must be satisfied when this question is answered. It will not be sufficient to assume an answer that will be suitable for one part of the phenomena but transgress the other part. When we remember that the physical features of the crystalline rocks, as they are found in the north-west, have not been even yet fully studied, and are far from being understood—not to mention discordance among those who think

they do understand them—it becomes apparent that it is not yet time to settle conclusively on any theory for the origin of the hematites of the Keewatin.

As we pursued the investigation of this problem we became familiar with the literature of the subject, and this has resulted in the preparation of another chapter in this bulletin on *the origin of the ores of iron*, in which the various theories which have been proposed for the existence of iron ores of whatever formation are classified, and a bibliography is added which, because it is the result of considerable study of this subject, not only has an indirect bearing on the problem presented to the Minnesota geologist, but will also be found serviceable to any student who encounters similar problems in any part of the country. In that chapter all the various theories are presented, and briefly discussed, and some inferences are drawn from the review on the progress and development of theory on the origin of ores from the time of Werner until now.

It is sufficient at this place to say that the writers have earnestly studied the possible applicability of all these theories to the Keewatin ores. They found but four of them that were within the range of possibility as an explanation of the Keewatin ores, and one of those was set aside as inadequate very soon after they attempted to apply it. We refer to that which considers the hematites as eruptive, that which considers them the result of chemical substitution of iron oxide for a carbonate, that which considers them as derived from original deep-sea deposits, and that which considers them a secondary product from the decomposition of basic rocks and the concentration of the iron oxide in drainage basins. These are included in Nos. 2, 8, 17 and 18, as the theories are classified, after Julien, on another page. The eruptive theory, (No. 2), the most prominently presented when we began the work, was duly considered first. The first year's work closed with insuperable objections heaped up against it, and these have multiplied as the study has progressed. At the same time, on the abandonment of the eruptive hypothesis, that of possible chemical substitution, after the formation of the rocks, of iron oxide for a carbonate, either of lime or of iron (preferably lime) was tentatively held and presented in the fifteenth annual report.* (Nos. 8 and 17.) Prof. Irving, who was at that date at work on the same problem, came to the same view, but considered that the original carbonate was that of iron, in the form of siderite.† Further examination in the field

* Op, cit. p. 246.

† Am. Jour. Sci. (3) XXXII, 255

and further study of the facts before ascertained, indicated that there could not have been such a substitution of iron oxide for lime, or iron carbonate, since the formation of the ore; but that the ore and the country rock were indissolubly allied in manner and time of origin, and that the ocean's waters which accumulated one must have coterminously deposited the other. By this time also the distinctness of the Keewatin formation from the Taconic (Huronian) had become established, and this allowed the consideration of the physical and mineralogical characters that distinguished the Keewatin rocks and ores to be dissociated from those of the later formation. The problem was reduced to finding a plausible explanation of the existence of iron, in any condition, in the waters of the Keewatin ocean. Considering the necessary character of the Keewatin waters, as indicated by the predominating character of the Keewatin sediments, it was plain that chemical causes would be the most potent to produce the ores of the Keewatin, and we had recourse at once to chemical reactions similar to those explained in a part of theory No. 18, which refers the iron to the decay of basic rocks. Still we had to construct a new theory, in part. We employed a portion of No. 3, which requires the ores to be formed as a deep-sea deposit, but we eschewed the agency of organic matter in the production of that deposit. This, not because of the probable non-existence of decaying organic matter at that time, nor because that agency would have caused the deposition in the bottom of the sea of a carbonate of iron instead of an oxide, but because we had presented forcibly before our minds a powerful chemical force existent in the heated and agitated Keewatin ocean itself. We had a continual volcanic supply of basic rocks coming continually in contact with the heated alkaline waters. The chemical reactions that must have ensued, we inferred, were the key to the problem of the origination of the iron in the ocean's waters and for its precipitation at the bottom of the sea among the accumulating sediments. The conclusion we arrived at was announced in a joint paper read before the American Association for the Advancement of Science, at the Toronto meeting,* 1890. It is believed to be the only theory that does not contravene any of the established principles of geological and chemical science, and at the same time accords to the physical structure of the rocks and ores and the conditions of Keewatin time their full force and significance.

Sufficient has been said concerning the origin and structure

* "On a possible chemical origin of the iron ores of the Keewatin in northeastern Minnesota." Published in November, 1889, in the *American Geologist*.

of the Keewatin rocks that enclose the ore bodies. Upon their nature is postulated the chemical environment which is supposed to have originated the Keewatin ores. The ocean was agitated by constant outbreaks of internal forces, which were accompanied by the basic ejections which the interior of the earth alone affords. The decomposition of the basic minerals was a rapid and continual process. The solutions went into the ocean's waters. The insoluble parts were distributed by its currents. Those also that were not wholly decomposed were laid down with the insoluble parts of the decomposed minerals. This was, necessarily, an "azoic" age, wherever this violent agitation and rapid transportation were in progress. Decomposing organic matter can be supposed to have played no part in the chemical reactions that may have precipitated the iron in the bottom of the ocean. There are reasons for believing that this oceanic condition was world-wide in Keewatin time, but they cannot be entered upon here. It is only necessary to inquire how such products as chalcedonic silica and hematite could have been formed in a sea that at times was seething and steaming with volcanic craters and earth-fissures from which escaped molten rock from below the crust. The descriptions that have been given of the ore and of its intimate relations with the silica bands of the jaspilite are ample to show that the method of accumulation of one was necessarily that of the other. While they are arranged by sedimentation, it could not have been the result of ordinary erosion and sedimentary transportation that gave these substances their origin. Ordinary sedimentation could not select from the products of erosion simply two substances and deposit them in regular lamination, in chemically pure condition. Some selective and ever-active force was at work which was able to extract these only from the over-charged Keewatin waters and reject all the rest. The product is almost chemically pure, for the variations in the jaspilite, whether in color or in composition, are due solely to variations in the relative proportions of silica and hematite. The exceptions to this fact are so rare that they may not be considered in stating the general principle, though they serve, like all exceptions and variations from general principles, as finger-boards that point the investigator to antecedent as well as subsidiary principles.

When the equilibrium of the surcharged waters was distributed by evaporation or by sudden cooling, such as would ensue when the currents carrying the solutions passed into hotter or into deeper portions of the area considered, a chemical precipitation would follow. This has been stated in the following words by De

la Beche*. "Surrounded by seas of inferior temperature, closing in upon the volcanic vents as the heated waters rose upwards, there would be a tendency to have certain substances, only soluble at a high temperature, thrown down, wherever the cooling influences could be felt; as also, when these substances may be borne upwards by the heated waters, to have them distributed by any oceanic currents acting over the locality, supposing that the heated waters either rose to or were produced at distances beneath the surface of the sea where these currents could be felt." This result would so obviously ensue that it is not necessary to quote any other authorities.

It remains to enquire whether the chemical precipitates that would thus be formed would be silica and iron oxide. Laboratory experiments might be made to demonstrate this. In the absence of such tests we shall quote the views of some chemical and physical geologists whose opinions will be more authoritative than our own.

On this point Hunt says:† The atmosphere, charged with acid gases which surrounded this primitive rock, must have been of immense density. Under the pressure of such a high barometric column condensation would take place at a temperature much above the present boiling point of water; and the depressed portions of the half-cooled crust would be flooded with a highly heated solution of hydrochloric and sulphuric acids whose action in decomposing the silicates is easily intelligible to the chemist. The formation of sulphides and sulphates of the various bases *and the separation of silica* would go on until the affinities of the acids were satisfied, and there would be a separation of silica taking the form of quartz, and the production of a sea water holding in solution, besides the chlorides and sulphates of sodium, calcium and magnesium, salts of aluminum and other metallic bases. * * * Quartz has not only never been met with as a result of igneous fusion, but it is clearly shown, by the experiments of Rose, that a heat even much less than that required by the fusion of quartz destroys it, changing it into a new substance which differs both in chemical and physical properties from a quartz. * * * * The first precipitates from the waters of the primeval sea must have contained ox-

*Geological Observer, 1851, p. 131. In this volume De la Beche presents and discusses many of the volcanic conditions and effects which the writers believe were characteristic of Keewatin time, and are exemplified by the Keewatin rocks more perfectly than by any others. Compare pp. 526-536.

†T. Sterry Hunt, *The chemistry of the primeval earth*, Am. Jour. Sci., Jan. 1858. Smithsonian Report, 1869, p. 189. Chemical and geological essays, 1878, p. 40.

idized compounds of most of the heavy metals. The large amounts of silica contained in solution in the waters of some thermal springs and of many rivers, are separated when these waters are exposed to spontaneous evaporation, partly as silicates of lime and magnesia and partly in the form of crystallized quartz, hornstone and opal. In many different formations beds are met with composed entirely of crystallized grains of quartz which have apparently been deposited from solution. In other sediments this element abounds in the form of grains of chalcedony, or as amorphous, soluble silica. The beds and masses of schist, flint, hornstone, buhr-stone and many jaspers have all apparently been deposited from aqueous solutions.*

Prof. A. Winchell thus refers to this primeval ocean and the precipitation of silica.† “The liberated silica would separate, and would be chemically precipitated during the subsequent cooling of the waters, and would thus give rise to the enormous beds of quartz which we actually find among the very oldest strata.”

Concerning the precipitation of ferric oxide Von Cotta says: “There can be no doubt that all true ore-beds were originally formed by mechanical or chemical precipitation from water. Their condition may have been much changed afterwards; thus under certain conditions hematite may have been formed from limonite.”‡ T. Sterry Hunt says:§ “Those chemical compounds which were most stable at the elevated temperature then prevailing would be first formed. Thus, for example, while compounds of oxygen with mercury or even with hydrogen, could not exist, oxides of silicon, aluminum, calcium, magnesium and iron might be formed. * * * * All the elements, with the exception of the noble metals, nitrogen, chlorine, the related haloids, and the hydrogen combined with these, would be united with oxygen. The volatility of gold, silver and platinum would keep them still in a gaseous condition at temperatures when silicon, and with it the baser metals, were precipitated in the form of oxides.” These quotations might be multiplied. The formation of siliceous and iron deposits from oceanic waters is referred to by Gustav Bischof,|| J. W. Dawson, and nearly all geologists who have written of the chemical reactions of the primeval ocean.

Some general reflections on the chemical reactions that neces-

*Hunt, *Geology of Canada*, 1863, p. 574.

†A. Winchell, *Sketches of Creation*, 1870, p. 59.

‡A treatise on ore-deposits. Translated by Frederick Prime, Jr., 1869, p. 22.

§Smithsonian report. pp. 186, 189.

||Chemical and physical geology (Cavendish Society), vol. i, pp. 143, 146.

sarily would follow from the conditions that are assumed for the Keewatin ocean may not be out of place.

If we consider the character of the rocks that constitute the crust of the earth, we shall find that silica and ferric oxide are omnipresent. Silica constitutes forty-five per cent of all the rocks of the earth's crust,* including limestones; and also nearly one-half of a normal basic tachylyte such as may be supposed to have cooled to form the earliest solid film that encased the earth. Its relative amount, in respect to the other elements of the earth's crust, has neither increased or diminished. It has undergone transformation, and it appears locally abundant or scant, but it is not destroyed nor lost. Whenever it appears as quartz it furnishes the most refractory element of the rocks. It is as quartz that it shows its dominance over all the other rock-minerals. It gives to the rocks structure, firmness, color, durability, and relative insolubility. There is no other element that is so quick and able to assert its distinguishing traits, and to stand independently among the influences and vicissitudes of chemical or mechanical change. Among the rock-making minerals it is the last to disappear in solution, and the first to present itself on re-crystallization. Its relative abundance, compared with the other acids, is so great that whenever the chemical bases are taken possession of by carbonic acid, which is primarily an element of the atmosphere, it is compelled to take up with any isolated and partnerless domicile that it can find in the clefts of the rocks.

Next to quartz iron appears as regent over the aspects of the mineral kingdom. Its advent in the earliest basic doleritic film, giving it the somber hue that denotes still the "greenstones," was the herald of the place it should hold throughout geological history. Notwithstanding the thaumaturgic feats by which chemical change has transformed the face of nature a thousand times, the presence and influence of iron are everywhere manifest. Whole formations are reddened by ferric oxide.† Were it not for iron every stone would be nearly white. The soils and subsoils would glisten with a painful whiteness. If all the known manganese in the world were confined in the surface soils, and to this were added all the copper and lead, all the silver, all the nickel and all the other coloring metals, the soils in the absence of iron would still be painfully and monotonously white, except where they might be covered, or colored, by decaying organic matter. As fer-

*De la Beche, Geological Observer, p. 527. It is estimated at fifty per cent by Dana, Manual of Geology, p. 49.

†Israel Cook Russell, *Subaerial decay of rocks, and origin of certain formations*. U. S. Geol. Survey, Bulletin No. 52, 1889.

ric oxide and hydrate iron has its stable conditions. These are the most frequent products of the chemical manipulations of the laboratory, and the most common results of the chemical changes of nature.

Therefore, in the problem of the origin of the hematite ores of the Keewatin, since they are intimately associated with the chalcedonic silica of the jaspilite masses, we have to do with two of the most abundant, as well as the most self-asserting of the rock-forming minerals—quartz and ferric oxide. It is evident, therefore, that if the volcanic conditions were such as we have supposed in Keewatin time, and the Keewatin ocean, in whole or in part, became charged with solutions of the minerals with which its heated waters came in contact, including silica and iron, in whatever chemical combination, and if then the change of cooling or of evaporation supervened so as to break up the equilibrium of perfect saturation, these two minerals would have been the first to free themselves from solution and to appear as precipitates on the bottom of the sea. They would have been not only the first but they would also have been the most abundant of the chemical precipitates. They would also have continued to accrete as chemical precipitates as long as the Keewatin conditions continued, and if the same conditions recurred in any later geological age the same chemical precipitates would have been the result.*

It is not necessary here to go fully into the subject of the chemistry of the primeval submarine volcanoes. De la Beche has presented† many of the conditions and considerations on which we have to rely to find the origin of the Keewatin ores. The classic work of Mr. Judd on volcanoes‡ may be examined by any one who desires to learn some of the more modern aspects and theories of vulcanology, and especially as to the physical laws and dynamic changes that, as geological agents, volcanoes illustrate. It is admitted on all hands that they are the seats of the most violent

* We have read with much interest the ingenious discussion of Mr. I. C. Russell, in Bulletin No. 52, of the U. S. Geol. Survey. He reaches the conclusion that the red color of certain formations is due to an incrustation of the sands during the subaerial decay of the rock from which they were derived. We think this explanation is inadequate. Not to mention the very problematic existence of lands sufficiently wide to furnish the ten or twelve thousand feet of strata that make up the Cupriferous strata in the state of Minnesota, and which extend from one side of the continent to the other, it is sufficient to call attention to the probable chemical precipitation of ferric oxide from the ocean in the same manner as above described for the Keewatin. The Cupriferous was a period of great volcanic activity. The same is true of the Newark. The strata of both are intersheeted as well as cut by basic rock which must have had its effect on the chemical status of the oceanic waters. The sediments of both are prevailing red, and in the Newark, in Pennsylvania and Virginia, are considerable beds of iron ore. Compare also J. W. Judd, *Volcanoes*, p. 74.

†Geological Observer, 1851, pp. 526-534.

‡Volcanoes; what they are and what they teach, New York, 1881.

chemical reactions, as they are also of the most stupendous of physical forces. The various acid gases that are emitted operate to convert iron, lime, and the alkaline materials in the rocks with which they come in contact into soluble compounds known as sulphates, chlorides, carbonates and borates. Such waters, especially if heated, are then capable of dissolving silica. They thus become the bearers of all the solid constituents of the rocks. They destroy the rocks already formed and then distribute their elements in new places, and in new forms and combinations. In Keewatin time these forces, conditions and changes must have been in a state of constant and intense activity.

(d.) *Distribution of the Keewatin and the Keewatin hematites.*

The rocks of the Keewatin, in the form of sericitic schists, graywackes, argillytes, agglomerates and chloritic schists, are widely distributed in Minnesota and Manitoba. The occurrence of iron ore is but one of their phenomena. Silica in the form of chalcedony is much more widely disseminated through them than iron ore. The geological map that accompanies this bulletin shows the area of the Keewatin in Minnesota. It is not yet possible to give any data for prejudging as to the possible existence of the ore lodes in this or that part of the stratification. It is not yet certain whether, at Tower and Ely, the chronological succession of the strata is from the south to the north or from the north to the south, although some internal evidence has been given under the head of "structure and character of the hematites of the Keewatin" that tends to indicate that at Tower the stratification ascends in the scale from south to north. The most that can be said concerning the distribution of the ore lodes in the Keewatin is summed up in the statement that *the ore uniformly accompanies the green chloritic schists, or the massive diabasic schists, whether these be agglomeritic or not.*

Outside of Minnesota the belt of chloritic schist which carries ore passes into Canadian territory by entering Hunter's island. There is great probability of the existence of valuable deposits of iron ore on Hunter's island, and also further northeast in the direction of their strike. In respect to other parts of the country we cannot speak with any positiveness. We do not know of the Keewatin schists anywhere else excepting northern Michigan, where the same lithology and the same geological relations are manifested about Marquette, and thence to Ishpeming and westward as far at least as the gold mines. Some of the Michigan mines, for example the Jackson mine* at Negaunee, are un-

*Foster and Whitney's report on lake Superior. Part ii. p. 54.

doubtedly in the Keewatin. Others, as the Buffalo, the Queen, the Sam Mitchell, near Negaunee, and others in that neighborhood, are with almost equal certainty in the Taconic (Huronian), which unconformably overlies the Keewatin.* That the Keewatin formation extends into Wisconsin there is great probability, but we are not sufficiently familiar with the iron regions of that state to speak with certainty. The mines of the Penoque-Gogebic range in the northern part of the state we do not admit within the Keewatin. See plate xv.

Further east there are no positive data for extending the Keewatin, although it seems to occur in western New England. It is possible that the dynamic change which is discussed in another part of this bulletin, whereby the Keewatin sediments and Keewatin ores were converted to Vermilion mica schists and magnetic ores, prevailed more extensively. The non-titanic magnetic ores of New York, New Jersey, Pennsylvania, Virginia and North Carolina, described as interbedded in gneiss and in mica schist, may be the cotemporary analogues of the Keewatin ores of Minnesota, though they are the lithological analogues of the Vermilion, as already described.

(3.) THE ORES OF THE TACONIC. (Huronian. *The Mesabi range.*)

Although there is at present no mining in these ores in Minnesota, they are well known at numerous places. They were indeed the first to attract attention, and were carefully surveyed and analyzed by Prof. A. H. Chester in 1875. They are destined to play a very important part in the future development of the iron industry of the state. They occupy fourfold the area that is occupied by the Keewatin ores, and they are nearer the ore-shipping points as well as the iron-using markets. It is on account of this high promise of future productiveness that they are fully described in this bulletin.

*Compare the seventeenth annual report, pp. 42-45.

(a.) *Reasons for substituting this name for Animike.* In the Minnesota reports the Animike formation has been described in several places.† The taxonomic relations it bears to other formations have been fully presented and need not be dwelt on here. Neither is it necessary to repeat the evidence that exists of its being on the same horizon as the Taconic. One of the most recent discoveries was that made by Mr. E. D. Ingall of the Canadian survey, announced by Mr. Selwyn.‡ This consists of fossils of Taconic types, which Mr. G. F. Matthew refers to radiate animals, or rather to their tracks, and names *Taonichnites*, also others that he regards tracks of a kind of squid or calamary and names *Ctenichnites*. These were found in the Animike rocks of Canada, north of lake Superior, and sufficiently establish the Taconic (Lower Cambrian) age of the Animike formation which has rested heretofore on general lithology and comparative stratigraphy. The proper name to apply to such a great rock-formation is determined by the law of scientific nomenclature by which that name which was first announced, with adequate description, is always required to be adopted. The term Taconic therefore may properly be substituted for Animike when the formation is referred to in any of its broader features or in comparing it with rocks of the rest of the world. As a local designation Animike will still be useful.

(b.) *Nature of the enclosing rocks.* (1.) *Macroscopic.* In northeastern Minnesota the rocks of the Taconic consist chiefly of carbonaceous and argillaceous, but often very siliceous slates and fine-grained quartzites and gray limestones. Sometimes the quartzites are coarse, and even become pebbly. Near the bottom of the series is a fragmental quartz-sandstone,§ which, having sometimes an apparent thickness of 300 feet, has been specially named Pewabic quartzite. What relation this quartzite bears to that portion of the slaty Animike which becomes conglomeritic, as on the northeastern shores of Gobbemichigama lake, it is impossible at present to state, but it is probable that the quartzite will be found to be nearly on the same horizon, or to be one of the

†Seventh annual report, pp. 9-25, for 1878.

Ninth annual report, pp. 61-82; 107-109.

Tenth annual report, pp. 85-88; 94-96.

Eleventh annual report, pp. 156-160; 162-170.

Thirteenth annual report, pp. 21-24; 124-140.

Sixteenth annual report, pp. 65-95; 233-292; 321-323; 352-359.

Seventeenth annual report, pp. 46-51; 77-110; 133-135; 186.

‡Tracks of organic origin in the rocks of the Animike group. *Am. Jour. Sci.*, xxxix (Feb., 1890), p. 145.

§See the eighteenth annual report. In previous reports the quartzite was supposed to lie over the Animike, and to be the equivalent of the Potsdam quartzite, but it is certainly older than the most of the Animike strata.

fragmental beds of that part of the Animike. When the Taconic beds are not horizontal, they dip southerly at all angles from three to ten or twenty degrees.

These slates, conglomerates and quartzites are profoundly affected by intermingled eruptive rock material. This eruptive material seems to have been supplied in a manner quite similar to that found so abundant in the Keewatin and which has already been described at length. It is found generally as fragmental, non-porous tuff, interstratified in the formation. There are some beds also that have the appearance of being consolidated beds of basic lava. In general, however, where these basic materials prevail there is frequently an insensible gradation from dark trap-looking beds to thin beds of slate. This character has been noted particularly on the shores of Loon lake, south of Gunflint lake. In cases where the Animike becomes more massive and at the same time conglomeritic, as in some parts of the shores of Ogishke Muncie lake, and on the north shores of Gobbemichigama lake, there must have been locally a rapid supply of such basic sediments. It thus makes a "slate conglomerate" similar to that of the Huronian on the north shore of lake Huron, of which probably it is the Minnesota equivalent. This should not be confounded with the agglomerates of the Keewatin, such as that seen on Stuntz island in Vermilion lake, and at Ely. Generally the Taconic can be distinguished from the Keewatin by the most evident characters—that of dip being the best guide. The Keewatin is always nearly vertical, and the dip of the Taconic is often very slight, and rarely exceeds 15 degrees.

The Taconic, in northeastern Minnesota, therefore, with some periods of quiet, was deposited in the midst of violent volcanic disturbance and oceanic transportation. It repeats, or rather continues, but on a much feebler scale, the physical characteristics of the Keewatin, but shows an increased amount of ordinary fragmental rocks. This similarity is not confined to the presence of basic sedimentary rocks, and their grading by insensible transitions to siliceous strata of very different aspect, but the same chemical precipitations which took place under such conditions in Keewatin time, also took place in Taconic time. In the Taconic (Animike) are frequent beds of flint, some of them being several feet in thickness, (Rock sample 1277), and this flinty texture, derived from the intimate mingling of chemically precipitated silica among the clayey sediments, pervades sometimes several hundred feet of the Animike strata. Besides flint, the Animike holds small quantities of jaspilite, banded and twisted, with thin

sheets of hematite, in a manner similar to that seen in the Keewatin. This has been noted at several places about Gunflint and North lakes, and also at the lower falls of Prairie river, near the town of Grand Rapids, on the east bank of the Mississippi (see rock samples No. 1295, 1310, 1315, 1529 and 1530). There is not however, so far as known, any workable deposit of iron ore of this character in the Taconic that can be compared to those iron lodes that exist in the Keewatin. There are thin and irregular deposits of jaspilite, styled in the 9th and 10th reports "Gunflint beds," some of them containing considerable quantities of hematite, as at the rapids of Prairie river, and much flint in regular layers, but in general the iron ore that exists in the Taconic in Minnesota is found in other associations, as will be shown later.

In respect to the carbonates, which exist in the vicinity of Gunflint lake, near the bottom of the Taconic, they seem not to be developed on so large a scale as they are in northern Wisconsin. About twenty feet of such cherty carbonate can be stated to occur, at the utmost, and even then it is quite impure with angular fragments of chert and flint. It is easily distinguished from all the other strata by the prevalent rusty coating which it carries. We cannot make out, from all the observations that have been made on the Taconic in Minnesota, anything more than a general description of the prevailing rock-strata, and some idea of their succession in the lower part. We have but little idea of the thickness of the lower parts, but feel certain that the whole series exceeds one thousand feet in thickness.

1. Basaltic trap and trap-like rock, at various levels, perhaps 200 feet.
2. Thin, carbonaceous black slates, perhaps 200 feet.
3. Gray, "feldspathic" quartzites, sometimes alternating with black slates, perhaps 200 feet.
4. Gray, impure quartzites, varying to black and green, alternating with and changing to massive trap-like beds, or variously blotched by green chloritic or hornblende ingredients and with magnetite, perhaps 100 feet.
5. Black slates and flint, or chert, banded coincident with the stratification, perhaps 30 feet.
6. Beds of gabbro and titanite iron, perhaps 200 feet.
7. Beds of vitreous quartzite [The Pewabic quartzite] interbedded with gabbro and sheets of hornblende or olivinitic magnetite, perhaps 100 feet.
8. Beds of dark massive conglomerate and breccia, "slate conglomerate," perhaps 200 feet.
9. Beds of carbonate of lime and iron, cementing a breccia of flint and jasper, perhaps 25 feet.
10. Beds of jaspilite, contorted as in the Keewatin, with specular iron intercalated, perhaps 2 feet.*

*Prof. R. D. Irving stated (Am. Jour. Sci. (3), xxxii, 252) that on the northern side of North lake beds of jasper reach an immense development, forming bold cliffs facing northward. And further northeast the bottom of the Taconic is characterized by immense beds of flint.

The above may be taken as a rough approximation to the thickness and order of the strata of the Taconic. These parts are not all continuous but give place to some of the others. For instance, Nos. 6, 7, 9 and 10 have each been seen lying unconformably on the Keewatin, or on the Laurentian, and No. 8 is so placed and enlarged sometimes, that it seems to monopolize the base of the formation and to absorb or at least obliterate the characters of the others that are frequently found near the same horizon. It is not certain indeed that it is not a part of the Keewatin.

Following is Prof. C. R. Van Hise's description of the parts of of the same formation as it occurs in northern Wisconsin and Michigan.*

The Taconic in the Penokee-Gogebic region.

"At the base of the series is a cherty limestone member which, in one place, is as much as 300 feet thick, and which varies from this to disappearance. The second member is a feldspathic quartz slate. On the average it is from 300 to 400 feet thick, and is composed of green, red and brown fragmental slates which contain a good deal of clayey matter. The upper part of this fragmental member is a pure vitreous quartzite, the induration of which has been due to the enlargement of the quartz grains originally deposited as a sandstone. The third member of the series is a belt of non-fragmental sediments about 800 feet thick, which is known as the iron-bearing member from the fact that all the known ore-bodies and heavily ferruginous rocks occur within it. The uppermost member of the series is a thick layer of graywackes, graywacke-slates, and mica-schists and slates. This member is several times as thick as the three lower combined, but in its essential fragmental character it is to be considered as a unit in the series."

With the exception of the uppermost member mentioned by Prof. Van Hise these parts have their equivalents in northeastern Minnesota, and even that may be represented in some mica-schists that have been described in the vicinity of Snowbank lake. The graywackes and mica-schists, however, that we have seen in Minnesota have been found to belong, with the possible exception just mentioned, to the underlying Keewatin and Vermilion series.

After this general survey of the rocks of the Taconic (Animike), it will be necessary to consider particularly the rocks that immediately embrace the ores of this formation. There are four methods

*Am. Jour. Sci. (3), xxxvii, 33.

of occurrence of the Taconic ores, as there are four distinct kinds of ore, viz:

1. The quartzose-hornblende (or olivine) magnetite group.
2. The impure jaspilitic-hematite and limonite group.
3. The carbonated iron group.
4. The gabbro-titanic-iron group.

These will be described separately. The first is the most important as a probable source of large quantities of merchantable ore in the near future. The second is interesting because of its genetic resemblance to the jaspilitic ores of the Keewatin. The fourth exemplifies the manner of occurrence of a large body of ores, the value of which, in Minnesota, would be enormous if there could be discovered some metallurgical process for their economic reduction, and the third represents in Minnesota what appears to be an important source of ore in the Penokee-Gogebic range. These occur distinctly and separately, in some places, and when fully characterized manifest features that do not occur in any two interchangeably. So far as these are iron-producing, in Minnesota, the ore is plainly indigenous and coëval with the formation of the containing rock, although there seems to have been a concentration of the ore and a coarser crystallization of the original rock-minerals in the case of No. 1, in some places, brought about by the heat of the great gabbro outflow, which is frequently in immediate proximity and, in the eastern part of the Mesabi range, may be considered to have extended over the whole.

1. *The quartzose-hornblendic (or olivinitic) magnetite group.* The non-titanic magnetic ores of the Taconic are principally found in the coarser parts of the Pewabic quartzyte (1308-9) or intimately associated with it. They are typically developed on the north shore of Chub (Akeley) lake. They are also associated with the occasional jaspilyte masses occurring at about the same horizon in the formation. The jaspilyte found on the north shore of Gunflint lake (1315) is thinly interleaved with magnetite instead of hematite. Considerable deposits of this ore, associated with an olivinitic quartzyte, extend all along the northern limit of the strike of the Pewabic quartzyte southwestward from Gunflint lake, as at Chub (Akeley) lake, Flying Cloud lake, Gobbemichigama lake (south shore), Frazer lake, Thomas lake, Birch lake, Iron lake, and thence westward to Pokegama falls on the Mississippi river. This is in general also the line of strike of the Taconic on its northern limit. The rock that immediately encloses this ore is primarily a fragmental, rather coarse quartzyte (1322) whose distinct rounded grains are evident to the unaided eye. It is by degrees modified

by the mingling of olivine or green hornblende or both, the latter appearing sometimes in nearly continuous layers or sheets coincident with the stratification, and affording coarse crystallizations (1339). These sheets are apt to be interrupted and to swell out suddenly. They are sometimes partly made up of vitreous quartz and the grains of the quartzite itself are coarse, glassy and apparently consolidated by deposition of secondary quartz (1338). The magnetite appears at first as isolated granules, sometimes showing its octahedral angles (but generally rounded) disseminated through the quartzite. It prevails over the quartzite more and more and becomes so abundant that the rock changes to iron ore. At the same time as the magnetite increases, the greenish mineral which is presumed to be olivine, as well as the fibrous hornblendic mineral, both appear. The rock then is heavy and dark-colored. The glistening crystalline cleavages of the hornblendic patches, and the separation of the now coarser crystalline grains of the magnetite, leaving their subangular basin-like depressions, affording the principal macroscopic characters. In other parts of the rock there is a scarcity of quartz, and the isolated magnetite grains are scattered through the hornblendic mineral. Here also they increase in frequency and break up the continuity of the hornblendic crystals, producing, when the rock is broken in certain directions, the granular aspect of a fragmental rock, and so becoming a granular iron ore.

These coarsely hornblendic and olivinitic characters occur in the easterly extension of the Pewabic quartzite, the former being characteristically developed in the region just west of Gunflint lake, and the latter in the region about Birch lake. Not enough study has been put yet upon the geographic distribution and the genetic and stratigraphic relations of these two iron and magnesian minerals in the Mesabi range ores to establish any principle touching their individual genesis or their correlation with the gabbro or with the magnetite, but there is evidently a reduction in the amount of these minerals at the horizon of the Pewabic quartzite toward the west, and on the Mississippi river they do not occur at all. It is noticeable that this diminution appears to be coincident with the greater divergence of the strike of the Pewabic quartzite from that of the gabbro sheet, the former going to Pokegama falls, and the latter to Duluth.

The Pewabic quartzite varies from a coarsely granular rock to a minutely fine one. In its finely granular condition it is as compact as chalcedonic silica, and cannot be distinguished readily from it in any way except that it is never white but varies to gray

and grayish-green and to darker colors. In this condition it is finely interlaminated, when ore-bearing, either with black magnetite and some greener sheets that may be parallelized genetically with the green schists of the jaspilyte lodes of the Keewatin, or with impure semi-hydrated limonite. In the latter case the ore is hematite-like and siliceous. It is as hard as a common knife blade, and it is with difficulty that a common knife blade can be made to scratch it enough to show the characteristic color of the ore (355 H). This condition of the quartzite is sometimes varied still further, by the conversion of the accompanying green element into actinolite (437). This seems to have taken place where the gabbro sheet has sufficiently affected it, or where some metamorphic agency has operated on the formation. It is a common feature on the Mesabi range in towns 59-14 and 60-13, and is frequent at Black River Falls, Wisconsin. The coarse and evidently fragmental phase of the Pewabic quartzite continues from Gunflint lake to Pokegama falls, and it is also interbedded with gabbro at Duluth, as revealed by the deep well at Short Line park,* whereas the fine-grained phase is known, so far as it is ferriferous, at points intermediate, and particularly in the country southwest from Gunflint lake and west of Birch lake. What may be the stratigraphic relations of these phases of this quartzite it is not possible to state. One may generally, or entirely, succeed the other, or they may have been produced locally and simultaneously, and hence at the same stratigraphic level—the coarse-grained phase being due to strong sedimentary and transporting agents, with weak precipitating reactions, and the fine-grained phase prevailing where chemical precipitation alone, or nearly alone, caused the siliceous accumulations. Both phases have been seen in immediate superposed contact on the older formations, and in some instances they are separated from the granite by a thin stratum of reddish and contorted jaspilyte. [Since the foregoing was written an important discovery of magnetic ore has been made by the Stone Iron company, in the Taconic on Sec. 18, 59—14. We have not been able to see it, but from samples sent, and from verbal descriptions we learn that the ore “appears to stand vertical” and the outcrop can be traced for nearly a mile east and west, “granite” lying both to the north and south. It runs across the S. E. $\frac{1}{4}$ of Sec. 13, 59—15, and on to the S. W. $\frac{1}{4}$ of Sec. 18, 59—14, passing northeastwardly into N. W. $\frac{1}{4}$ Sec. 18 not far from the center of the section. Samples received from Capt. W. Bice, who has charge of its development, show that the ore is probably in the

*See bulletin No. 5, p. 34. Natural Gas in Minnesota.

Taconic rocks, at least is in the quartzite known in this report as Pewabic quartzite. The "slate" which is from the north side of the ore is harsh and siliceous, like that seen in the bottom portions of the Animike about Gunflint lake, gray in color and slaty in the direction of the bedding, being actually a thin-bedded feldspathic gray quartzite of moderately fine grain, evidently of fragmental accumulation, with mica scales characterizing some of the bedding planes. The "slate" that comes from the southerly side of the ore is a dense, impure, dark, chalcedonic jaspilite, embracing considerable magnetite, in finely disseminated crystalline grains, also some pyrite, which, in some cases, is converted to limonite.

A magnetic belt has also been discovered running along north of the hematite belt in Sec. 3, 58—18.]

2. *The impure jaspilite-hematite-and-limonite group.* As an iron ore producer this group is not yet known to be important. The hematite-jaspilite beds that outcrop at the rapids of Prairie river, near the Mississippi river, are the most important that are known. This group repeats in the Mesabi range the same lithologic peculiarities that have been described for the jaspilite beds of the Vermilion range, but they are displayed on a small scale. The contorted outlines of the ribboned jasper are equally evident, but the ribbons are not so wide, nor so long. The colors are as brilliant, but they shade more quickly into each other. The red jasper is also occasionally blotched or peppered with varying proportions of hematite. Sometimes there is a homogeneous mixture, in form of round small grains of red hematite, disseminated through a stratum or a lenticular mass of blood-red jasper. The reverse is seen also, and the red jasper is scattered through a mass of red hematite. Even the best iron ore, (hematite) so far as seen at Prairie river falls, is flecked with siliceous red specks and veins, (compare 1527 and 1530). At the other end of the Mesabi range an outcrop of this parti-colored jaspilite was seen on the north side of Gunflint lake,* and it there lies immediately on the syenite of the Giant's range. By a slight extension of the significance of the term jaspilite it may be made to cover a large amount of the flint, oolitic jasper or bloodstone chert and gray quartz and quartzite with which the lowest part of the Animike is marked, in all the region of Gunflint lake. Generically and genetically these are the same. The difference of color is due to varying amounts of coloring material, (the chief being iron) and to difference of chemical combination. Indeed, if the chalcedonic condition of the silica which in many places characterizes the iron-bearing portion of the

*Sixteenth report, p. 73 and p. 242.

Animike, be allowed its full significance and the term jaspilyte be extended co-ordinately, we shall find the typical ribboned jaspilyte which gave origin to the term, undergoing a wonderful enlargement and metasomatosi. It extends upward and widely into the Animike strata, taking all the forms above mentioned and finally constitutes, either wholly or largely, the fine gray irony quartzytes, and becomes intimately mingled with the black slates that characterize the Animike in some places. The presence of organic matter, giving source to carbonic acid gas at the moment of the liberation of the silica has determined the condition and the color of the resultant siliceous rock.* This brings us to the consideration of

3. *The carbonated iron group.* This, as a source of iron ore in Minnesota is potential rather than actual, and it is here ranked on an equal scale with the forgoing because of its apparent great importance on the south side of lake Superior, especially in the Penokee-Gogebic range of Wisconsin and Michigan. Stratigraphically it lies below the jaspilyte horizon (No. 2 above) and apparently above the quartzose-hornblendic magnetite zone, or is wanting. This rock is represented by No. 312, and its chemical analysis, as reported by Prof. C. F. Sidener, is as follows :

Analysis of rock 312 (Chem. Series 215).

Silica	2 70 per cent.
Alumina.....	.35
Ferric oxide.....	17.23
Ferrous oxide.....	8.35
Calcium carbonate.....	49.80
Magnesium carbonate.....	19.65
Potassium oxide.....	.04
Sodium oxide.....	.20
Water .....	.47
Total	98.79

According to this analysis there is a large percentage of calcium-magnesium carbonate in this rock. But in many places the rock seems to consist more largely of iron carbonate. Compare also Nos. 1306, 1307 and 1310; also 16th report, pp. 71 to 72. The outward appearance as well as the hardness and the readiness with which it is changed to ferric oxide, as evinced by the rusty scale that it bears all over the exterior when weathered, point to a considerable amount of iron carbonate. Of this rock but few feet, (about 20) of thickness of strata have been seen, though there may be much more. If we may judge from the descriptions of Mr. E. D. Ingall, of the Geological Survey of Canada†, the Animike for-

*The new Mallmann mine, and the discovery of the Merritt Bros on Sec. 3, 58-18, both in hematite of this class, and in the Taconic rocks, are described at another place in this report.

†Geological Survey of Canada, Annual report, 1887-88, Vol. III, Part 2, p. 83 H. (Report on the mines and mining of Lake Superior, 1888.)

mation further northeast, in the Thunder Bay region, is very similar to the same in Minnesota in this respect. He states that the dolomitic portions, belonging in his "lower division," are only developed locally, although carbonates of lime and magnesia are distributed to some extent through the whole formation. Toward the southwest from Gunflint lake, although they have not been discovered in Minnesota, owing perhaps to the general prevalence of the drift, it is highly probable that they increase in amount. At any rate it is plain that they constitute that part of the Animike formation which gave origin and sustentation to the theory that was advocated by Prof. R. D. Irving,* and more lately by Prof. C. R. Van Hise,† for the origin of the "Huronian" ores of the lake Superior region, and there seems to be no reason except the scarceness of these strata and their generally level position in Minnesota and Canada, why the same horizon might not develop, on the north side of lake Superior, an equal amount of merchantable iron ore of like kind and origin.

This rock is gray, or light-gray, on fracture, with chalcedonic, flinty and jasperoid inclusions, but on its weathered exterior it is rusty, as already stated. It weathers away rapidly, and the flinty inclusions project beyond the rest of the surface. Sometimes the pieces included in the carbonated matrix are large, i. e., several inches or a foot in their larger diameter, and they are placed in discordant positions against the lamination of the strata, and in other cases they are very small and even so fine that they cannot be seen easily by the unaided eye in the general gray of the fresh fracture. Again the flinty and jasperoid portions are inter-laminated in parallel bands in the calcareous strata as if so deposited originally under the action of sedimentary agencies.‡ The siliceous fragments included in angular forms in this carbonated matrix manifestly must have been formed before the matrix that contains them. But the parallel and cotemporary formation of sheets of the same material within the matrix shows the continuance of the same cause and its interrupted action after the carbonated matrix had begun to be deposited. This siliceous material is undistinguishable in all its essential characteristics, from that seen in brecciated condition, and in inter-leaved ribbons, in the jaspilyte beds of the Keewatin, but here the carbonated ingredient takes

*Origin of the ferruginous schists and iron ores of the Lake Superior Region. *Am-Jour. Science*, (3), XXXII, 255.

†The iron ores of the Penokee-Gogebic series of Michigan and Wisconsin. *Am-Jour. Science*, (3), XXXVII, 32.

‡Compare the original description of an outcrop on Gunflint lake, tenth annual report, p. 87.

the place of hematite. The significance of this parallelism, in its bearing on the theory of the origin of the rock, and of the Animike ores of iron, will be referred to later.

Although the characters of the *carbonated iron group* are here described as belonging in their typical exhibition to the lower part of the Animike strata, it must not be understood that carbonates and carbon are wanting in the higher strata. The typical characters are not always associated in the same stratum. Indeed, in the higher beds they are more frequently separated, or are disguised. Carbon is, however, one of the most common and widespread of the pronounced characteristics of the Taconic. Carbonaceous slates, sometimes effervescent from carbonate of lime, make up a large part of the higher beds. Carbonaceous slates are interbedded with gray flint, the flint beds being from two to six inches in thickness (1277), but usually not far extended horizontally. Carbon in the form of graphite in pebbles and cakes from half an inch to an inch in thickness, is quite abundant in the metamorphosed slates and quartzites of Pigeon point (Nos. 270 and 552), and it is a common ingredient of some silver-bearing veins in the Thunder bay district (598). Some parts even of the *quartzose hornblendic-magnetite group* are invaded by the ever present element (carbon). There is a rapid effervescence in hydrochloric acid when some of the actinolitic magnetites (437) are moistened by a drop from a glass rod. Thus, in the same manner that the chalcidonic silica seen in the jasperoid beds extends upwards in disguised forms, so the carbonated element, its associate in the *carbonated iron group*, continues to be present throughout the Animike.

4. *The gabbro titanic-iron group.* There is certainly no iron ore in Minnesota which is known to exist in larger amounts than this. The explorer in the iron regions is continually finding this ore in immense masses, and it has been the cause of many visits by intending purchasers. Fortunately the lithologic characters that surround it are so simple, uniform and evident that the tyro may discern them. The belt that carries this ore is wide, and it extends from Duluth to Pigeon point, constituting, in its culminating topographic points, the summits of the *Mesabi range*.* The rock itself is gabbro, a basic eruptive, of gray color and generally

*It should be noted that the granite ridge, to which the term Mesabi is sometimes applied, is not the true Mesabi, but is known as the Giant's range. The Mesabi hills are formed by the gabbro range, and lie from ten to twenty miles south of the Giant's range. Compare 13th report, pp. 21 and 22. The Grand Marais Indians (Chippewas), hold a tradition that the great giant, *Mesabi*, is entombed in the hills north of Grand Marais, his head being represented by one hill, and his body, arms and legs being represented by other spurs and subordinate ranges. These hills are in the gabbro belt, and this traditional burial of the mythical monster is sufficient to show to which hill range the name should now be given.

of coarse crystalline texture. Its minerals are labradorite, augite, magnetite, biotite, olivine. The relative amounts of these minerals undergo great variation. While perhaps in no case will any of them be found entirely wanting, over large areas, they are, severally, sometimes so scarce, while at the same places some of the others prevail, that the rock takes on very contrary aspects. When the labradorite prevails, as about little Saganaga lake, and Bellissima lake, and in Carlton's peak, and in the feldspar masses that are embraced in the dark trap at Beaver bay, the rock when fresh is glassy, gray and firm, but on weathering it becomes almost white. When the magnetite prevails, as in the suburbs of Duluth, about the southern environs of Birch lake, at Iron (Mayhew lake), and many other places, the rock is black and firm, and simply becomes specked with lighter spots on weathering, the spots indicating the existence of crumbling crystals of labradorite. When the olivine or augite, or both prevail, which is apt to be accompanied by the appearance of crystalline masses of hornblende, and in cases of weathering near the water, the rock has a green or dark-green color, the green tint being increased by the conversion through weathering of some of these into serpentine, chlorite or delessite. In all cases of weathering the magnetite which constitutes the ore masses, and which nearly everywhere is to be seen in less quantity disseminated through the rock, is the most enduring of all the constituent minerals. It forms the roughness that is apparent on the surface of exposed knobs of gabbro, and on the complete destruction of the rock its grains remain undissolved and may be seen gathered, in favorable places on the lake beaches, forming local deposits of titanic iron-sand. This gabbro is found associated with red syenite, quartz-porphry and various sedimentary rocks in northeastern Minnesota, and, indeed, it passes through unimportant petrographic changes into the well-known "traps" of the Cupriferous formation, from which it has not yet been possible to separate it by any important lithologic or stratigraphic distinctions.* In this red rock, however, which may be seen in great display about Brulé lake and in the Misquah hills east from Brulé lake, and in general about the headwaters of Brulé river, there is not known to be any important body of iron ore. Magnetite, however, as one of the petrographic ingredients is found scattered through it in small amounts—whether titanic or not is not known.

While the stratigraphic relation of this gabbro and its associated strata, to the Cupriferous formation may not here be discussed, its

*See the Tenth Annual Report, p. 137. *Typical thin sections of the rocks of the Cupriferous series in Minnesota.*

relation to the other Taconic ores, as exemplified in northeastern Minnesota, is well known and can be expressed. It was supposed by the geologists of the late Wisconsin geological survey that the gabbro eruption, in the main, took place after the completion of the Animike strata, and that it formed the base of the Keweenawan, fading off upwardly, by a succession of traps and sandstones, and with interbeddings of conglomerates and volcanic tuffs into the most characteristic features of the Keweenawan. This view has also been held by all the Minnesota reports except the eighteenth. But it has been found that the great gabbro flood of northeastern Minnesota was outpoured at an earlier date. In the sixteenth annual report* will be found evidence that it began during the deposition of the Pewabic quartzite, and that it followed immediately after the body of that quartzite had been laid down. This quartzite is believed now to belong at the bottom or near the bottom, of the Animike, although it was at first supposed to be the equivalent of the Potsdam (Paradoxides horizon) which apparently overlies the Animike. The gabbro being intimately associated with this quartzite must follow it to the lower portion of the Animike, and hence to near the commencement of the Taconic so far as the Taconic is developed in Minnesota. At the same time the term *Pewabic quartzite* is supplied with a geological *raison d'être*, since it is no longer possible to make it the parallel of that quartzite which is supposed to overlie the Animike, viz: the Wauswangan-quartzite, nor of any of its equivalents—whatever they may be.

The gabbro, with its capriciously distributed titanic masses, therefore, being of about the same age as the non-titanic ore masses of the Pewabic quartzite, and having been poured over the quartzite, and having embraced large disturbed portions of the Pewabic quartzite in its own mass, some of which might be turned up so as to stand nearly vertical,† will be found to present some confusion and variety as to the quality of the magnetic ore which it may hold. Such is the fact. It will not be safe to infer that because a magnetic ore body is contained within the general area of the gabbro it is therefore to be condemned as titanic, although that would generally be correct. It may be non-titanic and derived originally from the Pewabic quartzite, or from some other part of the Animike, and it ought to be inspected carefully by one familiar with the distinctions between titanic and non-titanic ores, and as a final test it should be examined chemically for titanium. Such exotic magnetites within the gabbro can generally be detected by

*Pages 85, 88; 17th Report, pp. 52, 53; 18th Report, pp. 43-47.

†Seventeenth annual report, p. 96.

their having more or less quartz connected with them, or by some remaining trace of a sedimentary structure in the adjoined rock.

The structure of the gabbro is generally massive, rising in low rounded hills and spreading over a large tract of country. Occasionally a gneissic (laminated) structure is seen in it. Such occurs on the east shore of Birch lake where a conspicuous hill is marked by parallel weather-lines sloping toward the south, the lines being due to the weathering out of the contained olivine which is disseminated in alternating sheets of greater and less prevalence throughout the hill. It is shown in figure 15. The dip is



FIG. 15.—Bluff of gabbro having a gneissic lamination.

42 degrees. Another recorded observation of a bedded condition of the gabbro is found in the tenth annual report (rocks 810 and 814), page 111, on the lake Superior shore two and a half or three miles east of Beaver bay. This gneissic structure is not due to shearing pressure nor to sedimentation, but to a varying abundance of the more easily decaying minerals, such variation occurring in sheets and on the weathered edges appearing as depressed lines or grooves.

Since the gabbro in its petrographic characters apparently shades off into common doleritic trap, and into diabase, it is possible that it had other epochs of outflow, and also that what is gabbro at one place, at any stratigraphic horizon, may not be well characterized gabbro at another place. Hence there may be gabbro or gabbroid traprock, of much later date than the Pewabic quartzite, and it may lie on any of the later strata of the Animike. Yet, notwithstanding this consideration, there is much evidence that the principal outflow of that coarse basic eruptive which is well represented at Duluth by the "Rice Point granite" or gabbro, and which is accompanied by acid eruptive rock, was of the age of the lower Animike, and took place immediately after the Pewabic quartzite.

(2) *Microscopic characters of the enclosing Taconic rocks.* (a) *The rocks of group No. 1. The quartzose hornblendic (or olivinitic), magnetite group.*

Interbedded with the Pewabic quartzite, at Chub lake, NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ Sec. 29, 65-4, are thin layers of basic materials (1339) which

have the appearance of having been followed immediately by coarser sediments of almost pure fragmental silica (1338). These two rocks were examined in thin section and described below. The origin of this basic material must have been quite similar to that of the green schists of the Keewatin, viz., volcanic ejection, and its dispersion due to the prevailing oceanic waters. Its nature shows its close genetic alliance with the schist that embraces the ores of the Keewatin.

Rock 1339. This is a compact lherzolyte chiefly composed of yellowish-green enstatite, olivine and magnetite, but presenting considerable variations, even in the same hand-specimen, passing from a fine schistose condition into a coarse crystalline (like noryte or gabbro) while in some of its modifications it assumes the character of a regular quartzite. A section prepared from the dense, fine-grained schistose type shows an admixture of well defined tabular plates of rhombic pyroxene (enstatite) of yellowish green color and granular or "fractured" olivine of a paler shade of green, without the yellowish tinge. The enstatite plates exhibit, in most instances, an exceedingly fine striation, or division into parallel fibres; are comparatively free from cracks, and contain no enclosures of foreign minerals, except a few occasional grains of magnetite. They polarize in lively colors, (chiefly red and green) but show no pleochroism if tested with the lower Nicol, thus manifesting their essential difference from hornblende. The olivine is present in the form of angular masses and grains, and predominates over the enstatite. It is in a singularly fragmental or "shattered" condition, full of cracks, which do not appear as if due to the ordinary fissuration of olivine, (in its transition into serpentine) but to a cause which acted rapidly, such as mechanical pressure or a sudden thermal disturbance. Cracks of this kind would be produced in glass or rock-crystal, if suddenly heated or immersed in cold water after heating. If the cracks in this olivine were due to serpentinization we would naturally expect them filled with chlorite or glauconite as necessary alteration products (as is invariably the case with olivine affected by serpentinization). Instead of this, the olivine fragments, though full of the usual enclosures (glass-cavities, magnetite, picotite) are comparatively free from decomposition-products and have retained their optical properties so well that the polarization colors are almost as brilliant as those of clear olivine.

The magnetite occurs in the shape of rounded grains and crystals, varying from dust-like minuteness to aggregates equalling in size the largest of the enstatite tablets.

That an ultra-basic olivinous rock like lherzolite should be found interbedded and in contact with quartziferous masses, and should actually pass into an unmistakable quartzite, is, to say the least, remarkable.

Rock 1338. As one of the modifications, or local variations, of the basic type, described under 1339, this rock is peculiarly interesting. It is a well-characterized quartzite, being composed of quartz-grains, magnetite and an interstitial substance of doubtful character, which may be altered muscovite. The quartz grains are mostly large and do not seem much waterworn, presenting angular outlines, though not as sharp and fragmental as in the Triassic sandstones. That they are part of the detritus of some ancient granite cannot for a moment be doubted as they have all the characteristics exhibited by the quartz of granites. They are full of fluid-cavities, which are usually arranged in lines, parallel, or nearly so, with one of the planes of crystalline growth. If we examine these enclosures with a good $\frac{1}{4}$ or $\frac{1}{8}$ inch objective we observe in the smaller ones a lively vacuole-motion, while in the larger cavities the bubbles appear stationary. Beautiful yellowish dendrites of hydrated iron peroxide (as seen in moss-agates) are found here and there, lining the cracks.

The interstitial substance is not a mere amorphous paste, cementing the quartz grains, as one might be tempted to conclude, or an infiltration product, but an undoubted primary component, and in the writer's opinion, it was a constituent of the same granite which furnished the quartz. Its color is a yellowish-green, sometimes brownish, the latter indicating a more advanced stage of decomposition. It polarizes in remarkably brilliant tints of red, green and yellow, so that each quartz grain appears as if surrounded by a beautiful fringe of multi-colored ribbons. We notice the same peculiar banded structure in the muscovite of granites (also in sericite), and as neither hornblende nor any kind of rhombic or monoclinic pyroxene (especially if in the least decomposed), shows such intense polarization-colors, we may look upon this greenish, interstitial component as an original muscovite, rendered fibrous and stained by ferric hydroxide. The magnetite, of which this rock is largely composed, occurs in the shape of grains and symmetrical crystals, which sink down to dust-like minuteness; some are wedged in between the quartz grains, others are enclosed in the latter. The crystals, grains and aggregates present well-defined boundaries, and not a trace of the usual hydrous decomposition is observable.

The foregoing described samples (1339 and 1338) were from near

the bottom of the Pewabic quartzite. The next (437) was taken from some higher quartzose strata on the Mesabi range, near the section line between sections 14 and 15, 59-14, at one of the old test-pits, opened by Prof. Chester's party. This specimen effervesces freely, and the carbonate present was supposed (in 1878, 9th report, p. 108) to be siderite. But it is quite likely that it is due to secondary calcite, as the effervescing is free on weathered surfaces, and feeble on fresh fracture. This is a common rock in the iron-bearing strata of the Mesabi range, and it also occurs abundantly in the iron-bearing strata at Black River Falls, Wis., as well as in the Penokee-Gogebic range.

Rock 437. A grayish amphibolyte, which appears to be exclusively composed of actinolite and magnetite. The actinolite is characteristically developed in pale green fibres, which intersect each other at various angles, though never so as to give rise to distinctly radial aggregates. The fibres show a very feeble pleochroism, but they polarize in lively tints of green, blue and yellow, especially in the clearer portions of the field. The magnetite is not evenly distributed in this rock, but occurs in nests or patches, each consisting of a dense aggregate of opaque granules, but isolated particles of magnetite are also noticeable among, or between, the actinolite fibres. The actinolite, there can be little doubt, is an alteration-product, but whether the parent mineral was ordinary hornblende, or one of its rarer analogues, cannot now be satisfactorily established. The writer is inclined to consider it a modified tremolite, as it comes nearest to that mineral in its behavior between crossed Nicols, showing stronger polarization colors and feebler dichroism than any other amphibole variety.

The microscopic characters of the rocks that are associated with the *impure jaspilitic-hematite-and-limonite group* have not been studied. They cannot differ very much from the characters indicated in the description of their megascopic features.

A single sample (312), representative of the third phase, the *carbonated iron group*, has been examined in thin section. This was obtained from the north shore of Gunflint lake, where it acts as the matrix of a quartzite and flint breccia, or conglomerate. (Ninth report, p. 82; 10th report, p. 87). Compare Nos. 1306, 1307 and 1310.

Rock 312. A massive dolomite of light gray color, with a faint greenish tinge, homogeneous and compact in some of its samples, while in others (1310) it assumes a porphyritic structure and almost passes into a conglomerate, being intermixed with a dark

soft shale and with pebbles of greenish chalcedonic silica. In the section prepared from the dense homogeneous variety (312) we observe the usual granulation of massive dolomite, the granules being entirely devoid of the striation invariably exhibited by calcite, but never by a magnesian carbonate of lime. Many, if not most, of the granules are irregular in outline, flattened, fractured or pressed out of shape, but in numerous instances we still distinctly observe the rhombohedral forms which are so persistently manifested by dolomite crystals, even when occurring in dense aggregates. The chalcedonic masses embedded in this dolomite do not appear to fill or line original cavities and fissures in the rocks (which would imply a secondary origin), but seem to have been mechanically introduced during the deposition of the matrix. They have all the characteristics of water-worn pebbles, and it is extremely probable that the black slaty fragments (chlorite-schist?), noticeable in 1310, were likewise derived from a foreign source. All the structural features of this variable rock point to a period of considerable local disturbance during its formation.

The microscopic characters of the rocks of phase No. 4, *the gabbro titanic-iron group* are those that have been ascribed to the gabbros and the augite syenites of the gabbro series. They were described in a paper read before the American Association for the Advancement of Science at Cincinnati, *and have been more amply described and illustrated in Bulletin No. 2 of the survey, by Dr. M. E. Wadsworth. It is not necessary to dwell on them here. The titanic ore is one of the primary constituents of the rock, and is disseminated through it in all relative proportions, only making ore where it exists so as to nearly exclude all the other minerals. Sometimes the labradorite excludes all the other minerals in a similar manner, making a beautiful labradorite rock. Apatite, which is found uniformly in this rock in microscopic amounts, is another of the primary ingredients, and increases in amount in a remarkable manner, and probably constitutes, in Ontario, the extensive "phosphate deposits" of the so-called Laurentian, which have been supposed to prove the existence of organic matter in the Laurentian age, but which recently, Mr. E. Coste of the Canadian survey, has unequivocally assigned to its proper origin. (See the Bibliography.)

(3). *Structural features of the ores of the Taconic.* As there are at present no productive mines in operation in the Taconic ores in Minnesota, there is not so favorable an opportunity to learn their structural features as there is for those of the Keewatin. It

*Proceedings, Vol. XXX, 1881, p. 160.

will be necessary, therefore, to confine this description to such observations as can be made on the outcrops and excavations that have been visited, and the samples that have been collected. Some details not here included will be found in the ninth, thirteenth, sixteenth, seventeenth and eighteenth reports.

The ores of group No. 1—the *quartzose-hornblendic (or olivinitic)-magnetite group*—are well characterized. They are in sheets that coincide with the dip of the nearly horizontal quartzite beds that are associated with them, and their thickness, perpendicularly, appears not to be great; the greatest reported stratum being twenty feet thick. Sometimes several strata of iron ore are encountered, separated by quartzose beds, in which the ore is too lean to be of merchantable grade. The ore has a compact texture, brilliant lustre and closely perpendicularly jointed structure. The last makes it easy to break up into small angular, cuboidal or parallelopipedon forms. It also preserves a rude horizontal lamination (1308) by which the blocks acquire their upper and lower planes, due to the sedimentary structure implanted on it when it was formed. This is the character of samples obtained near the east end of Gunflint lake on Capt. Sedgwick's survey (Canada side). In some places contiguous, the ore is affected by olivinitic material slightly pyritiferous, and fades out gradually into a flinty-granular, yellowish, or often rusty, olivine (?) rock in which, while olivine is the chief constituent, there are evidently present also some pyroxenic mineral, some magnetite, and some micaceous scales (1309).

At the ore locations a few miles west of Gunflint lake (on secs. 28, and 29, 65-4 W.) the quality of the ore is very similar to that just described, and it has the same structure and stratigraphic relations. It lies but a few feet above the gneiss of the Giant's range which runs east and west as a conspicuous hill-range less than a mile north of the outcrop. A shallow shaft that penetrated the ore at one point encountered this gneiss. The ore is inter-stratified with the fine gray (feldspathic? and) quartzose material that makes up so much of the lower part of the Animike, usually styled gray quartzite, and seems to have this also as its principal admixed impurity. Curious black, amorphous, lenticular masses, somewhat flattened with the stratification, from half an inch to three or four inches in larger diameter, encroach upon the iron along certain of the sedimentary planes. At other times there is much coarsely crystalline hornblende associated with the rock and the ore (452 H, and 453 H). Some of it is also strongly pyritous, the sulphide mingling with the magnetite and the quartz grains and having a light bronzy lustre suggesting the possible presence of nickel.

Numerous observations have been made on this ore further toward the southwest, the details of which are given in the seventeenth report, and need not be repeated here. Suffice it to say that it seems to become olivinitic, especially in those outcrops which lie nearest the bottom of the formation, and, in general, therefore, furthest north, and less hornblendic. These deposits are also the most important and more coarsely crystalline. Those iron strata that occur higher up in the formation are less valuable, so far as observed. They are mixed, sometimes quite irregularly and capriciously, with siliceous rock material, and with fine-grained greenish siliceous bands. The magnetite winds out and in and crosses these siliceous parts, or it branches without any apparent reason or order. Fig. 16 was sketched to show this manner of the magnetite, seen in a perpendicular bluff of Animike strata in N. W. $\frac{1}{4}$ sec. 24, 60-13, southwest from Birch lake.

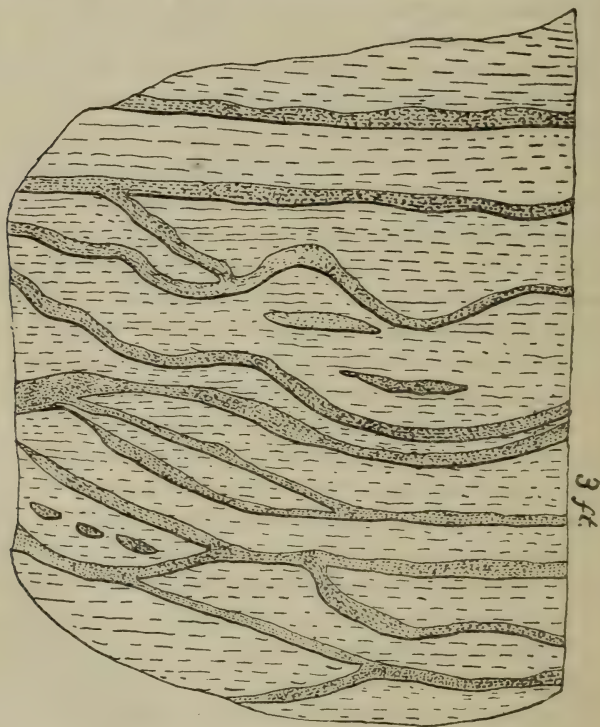


FIG. 16.—Veins of magnetite in greenish Animike rock.

The magnetic quality of the non-titanic ores of the Taconic is known to extend but feebly as far west as the working of the Merritt Bros., sec. 3, 58-18, which is twenty-three miles west of the point where the Duluth and Iron Range railroad crosses the Giant's range,

and there is nothing known of it further west. It appears that there is a gradual change in the nature of the ore toward the southwest and west, as evinced in the strata of the Taconic (Animike), by which the magnetic quality is diminished, and that in place of magnetite the formation contains hematite and limonite. In some of the explorations that have been made in towns 59-14, 60-12 and 60-13, magnetite (with actinolite) and limonite are both found.

The ore that occurs in connection with the second group of lithologic characters—the *impure jaspilitic-hematite, and limonite group*—is the Taconic analogue of the hematites of the Keewatin, and its original mineral associations, as well as its present structural conditions, are essentially the same. The jaspilyte is contorted and irregular. The silica is chalcedonic and parti-colored, but its colors are seldom (indeed never) seen so ribbon-like and extensive. Rather the red appears as streaks or round follicular spots in the brown, or in the flinty silica. Also clear watery globules of transparent silica are distributed closely through a red jasper or a gray flint; or, *vice versa*, blood red spots the size of a pin head are thickly crowded in a pellucid matrix. These variations are the noticeable features, and they coincide with the inference that may be deduced from the comparatively small amount of this jaspilyte, to the effect that the force that produced this Taconic jaspilyte was of less duration than in the Keewatin and acted under conditions that cramped and interrupted its normal result. At the east end of the Mesabi range, where the ores in this formation are, so far as known, all magnetic, this jaspilyte contains a small amount of magnetite. In the central part of the range it cannot be recognized as jaspilyte in the ordinary use of the word, but it is a greenish quartzose rock of very fine grain irregularly streaked with limonite; and at the west end (on Prairie river), with a development of typical banded jaspilyte, the associated ore is hematite. In an enlarged sense, however, the jasperoid element is found to pervade a great thickness of strata, and the limonitic beds of the central area may be said to occur in chalcedonic, greenish and yellowish silica that had the same origin as the red and gray banded beds at the extremities of the range. These jaspilyte beds, especially those seen at the eastern end of the range, while in the main conformable in dip with the accompanying beds of the formation, are still more variable in small patches than those beds. They pass from horizontal to dips in diverse directions (1315). They have a fine fluidal or “streamed” structure. This fine alternation is also visible often in strata higher up, in some magnetic black beds (362 H), the origin of which would hardly have been understood but for the information

and the results derived from this investigation. Those black banded magnetic siliceous beds graduate, apparently, on the one hand into the typical jaspilite beds, and on the other into the greenish siliceous rock that is banded by limonite.

The ore of the *carbonated iron group* (No. 3) in Minnesota is at present entirely a hypothetical possibility. It seems to be that which is so largely developed in the Penokee-Gogebic range on the south side of the lake, and should it be found in Minnesota it is to be supposed that a conjunction of circumstances similar to that described by Prof. C. R. Van Hise * for Wisconsin would also be found. Briefly stated, there are three of those conditions which seem to be essential to the occurrence of ore of like kind and genesis on the north side of the lake, viz. 1. A considerable thickness of carbonated strata, preferably largely of siderite, but possibly of lime and magnesia. 2. A cutting of those strata by perpendicular eruptive dikes, the more numerous the better, prevailing in one direction. 3. The tilting of the strata, with their contained dikes, in a direction parallel, or approximately parallel, with the prevailing direction of the dikes. It would require, according to the theory of Irving and Van Hise, only the lapse of time and the continuance of natural meteoric forces to produce, *along the troughs formed by the dikes and the strata which they cut*, an accumulation and concentration of peroxide of iron through the change that would be wrought in the carbonates of the original Taconic strata. According to Van Hise's observations the valuable deposits of iron ore found in the Penokee-Gogebic range have this relation to the dikes and the strata, and will be found to run out or to be wanting entirely, on the lower or opposite sides of such troughs. We have no disposition here to question this hypothesis. We only wish to show where it is applicable in our classification and where it may possibly be identified. The Animike strata are highly tilted in the region west of Gunflint lake and to Gobemichigama lake, and perhaps in other places where they are covered by heavy drift deposits. Dikes occur generally, but they have not been noticed to bear that angle complementary to the dip which has been represented in Wisconsin. Should it be proven, however, that the Animike strata contain, near their base, a large body of carbonated iron, or of lime and magnesia, it is very likely that they will be found cut by dikes and changed as described by Van Hise. Further west in every place where these strata have been seen they are not so much tilted, but they might still be upheaved

*Am. Jour. Sci. (3), xxxvii, 32.

enough to produce the necessary conditions for the concentration of the ores in such troughs.

[Since the foregoing was written two important discoveries have been made of hematite ore of this class. One is on Sec. 11, 59-14, and is known as the Mallmann mine. The other is on Sec. 3, 58-18, and is owned by the Merritt Brothers. At another place in this report the Mallmann mine is described and a generalized section north and south at the same place as shown in figure 26. The Merritt discovery shows a perpendicular thickness of ore of at least 27 feet, the southward dip being about 30 degrees. There is a little bluff of magnetic quartz schist about 150 feet to the north of the ore, and the ore probably overlies that. The granite belt is about a mile further north, constituting the "high of land." This deposit has been traced at least 1,000 feet east and west. The downward succession in the strata appears to be as follows:

The great black slate formation.

Iron bearing rock, hematite.

Slate, grayish, some of it black, say 15 to 20 feet.

Quartzite with magnetite ore.

Conglomerate.

Granite of the Giant's range.

This succession, and all the lithology, are repetitions of the Penokee-Gogebic iron range in Wisconsin.]

The *gabbro titanic-iron group* of lithologic characters has been described. It is only necessary to say here that the ore is a black, massive magnetite, generally of coarse, hackly crystalline fracture, and when pure and in large quantities, as it is frequently, it appears in bold and bald knobs, and is dispersed irregularly through the gabbro of the Mesabi range.

It seems to be only a highly magnetited condition of the structureless gabbro rock itself. This ore was first seen by the officers of the survey at Mayhew lake, north from Grand Marais.* Mayhew lake is sometimes known as Iron lake. It is south from Gunflint lake. A careful field-study of the appearance here gave origin to the following conclusions, from which we have not found it necessary to deviate in our subsequent study.

1. The ore is in the igneous rock.
2. It varies in quality very much, even passing into rock that cannot be styled iron ore.
3. It involves with itself nodules of coarse gabbro containing considerable magnetite (696).

*Tenth annual report, page 80.

4. It also embraces isolated pieces of [gray quartzite?] (698), but which in thin section are seen to consist of plagioclase, magnetite and augite; and some dark crystalline micaceous nodules (697). [This is apparently a condition of the rock we have latterly styled *muscovado*.]

5. It dips toward the south in beds whose aggregate thickness is at least fifty feet, but may be seventy-five, the actual amount being hid by a swamp.

6. It involves, also, detached masses of coarsely crystalline gabbro nearly free from magnetite, but containing biotite.

7. It sometimes gives place to a coarse trap of the same kind which is so large in amount as to constitute the rock of the place, and its connection with the ore cannot be seen. Samples of this coarse, micaceous trap are 699.

8. It lies on a fine-grained rock (700) like 698, containing chrysolite, resembling a granular fragmental rock, whose apparent dip, due to a deceptive columnar appearance, is toward the north. (Compare 677).

This iron is in considerable but unknown quantity at this place, and appears in a similar manner in many places in the vicinity of Mayhew lake, toward the southwest and west, as well as toward the southeast. This ore may also be seen in the gabbro within the corporate limits of Duluth, where it appears simply as a very highly ferruginous condition of the gabbro, with the other gabbro minerals as its impurities. There is no place within the area of the gabbro sheet where this ore may not exist, as its appearance is entirely fortuitous, but its quality varies from nearly pure magnetite (or menaccanite) to simply magnetitic gabbro.

(c). *Distribution of the Taconic Rocks.* From the northeast the Animike formation enters Minnesota with a width on the international boundary of about sixty miles. The typical Animike strata are the slates and quartzites, and the conglomerates that are developed in their basal portions. But the gabbro is of the age of the lower quartzite, and that, and the other basic, interbedded traps, must be included in the formation as a whole. These rocks extend southwesterly toward Duluth and reach the Mississippi at Pokegama falls and at Little Falls. This general trend is divided apparently into two belts by a central anti-clinal of the older formations, the southern spur passing with the gabbro under the waters of the St. Louis river and bay at the west end of lake Superior, and becoming lost under the later lake Superior sandstones and only re-appearing (in Minnesota) far toward the southwest

where (at New Ulm) it emerges again and extends to the southwest corner of the state. The other spur, reaching Pokegama Falls, runs southwestward along the westerly side of the older anti-cline mentioned, as far south, at least, as Little Falls in Morrison county where it has an unconformable position on some Vermilion mica schists,* and thence southwestwardly apparently fades out by the general uprising of the granitoid rocks. Nothing very definite can be said of the boundaries of these spurs, owing to the abundance of the drift-sheet, but this duplication of the strike of the Taconic strata is pretty well proven by isolated outcrops of this and the older formations which cannot be properly correlated in any other way.

(d.) *Geological relations of the Taconic rocks.* The reader will have inferred from the preceding description that the formation succeeds the Keewatin chronologically, and that it represents, in general, the time of the primordial fauna. There must have been a great improvement in the life-supporting conditions of the ocean, for, while there was still an occasional eruptive disturbance from which poured forth volumes of gabbro and other trap rock, there were still long periods of quiet during which life flourished. This is attested by the preponderance of carbonaceous slates, and the occurrence of carbonates of iron and lime and magnesia. An iron carbonate is the product of chemical precipitation in the presence of an excess of carbonic acid—otherwise the iron precipitate will be ferric oxide, as in the Keewatin. Organic matter is ordinarily required in order to extract carbon from the atmosphere and store it in the rocks in any condition. If in the form of carbonic dioxide it unite with lime or iron it may be precipitated in large quantities, in the bottom of the ocean, making important strata in the super-crust. If it be accumulated as free carbon, it will appear as plumbago, or when impure as carbonaceous matter staining the slates that contain it.

The Taconic strata in Minnesota are uniformly unconformable on the underlying rocks—whether of granite, greenstone, gray-wacke or mica schist. This observation is found to hold true from Thunder bay, in Ontario, to Little Falls and Pipestone in Minnesota,† and generally their dip is less than twenty degrees.

(e.) *Nature and origin of the Taconic ores.*

The ores here embraced in the Taconic [Animike] are of three kinds, viz :

*This is the first announcement of this unconformity at Little Falls. It will be studied more fully and reported later.

†In this statement the Sioux quartzite may be considered the equivalent of the Pewabic quartzite but we do not consider that equivalence is established.

Black magnetites from the Pewabic quartzite.

Hematites (often limonitic) from the jaspilitic beds.

Titanic magnetites from the gabbro.

These are all found in the Mesabi range.

Of these the first is the most promising for a supply of ore for use in the immediate future. The second is the lithological Taconic representative of the Keewatin hematites and the exact parallel of the Gogebic hematites, and the third is known to occur in the greatest amount.

Chemical Composition. Following are chemical analyses of the Pewabic magnetites :

From N. W. $\frac{1}{4}$ sec. 23, T. 65-4. (west end of Gunflint lake).
(By Rattle and Nye, Cleveland.)

Metallic iron	55.600
Silica	10.020
Phosphorus	0.042
Manganese	4.340
Alumina	0.340
Titanium	None.

From N. E. $\frac{1}{4}$ N. E. $\frac{1}{4}$ sec. 29, 65-4. (west of Gunflint lake).
(By Rattle and Nye, Cleveland.)

	No. 1.	No. 2	No. 3.	(average of 6 samples)	
Metallic iron	58.40	54.01	63.98	"	"
Silica	8.22	9.37	8.90	"	"
Phosphorus	0.36	0.32	0.28	"	"
Manganese	4.92	5.02	none	"	"
Alumina .....	.52	.07		"	"
Titanium	none	none	trace	"	"

From N. E. $\frac{1}{4}$ sec. 23, 60-13. (near Iron lake).

(By C. F. Sidener.)

Silica	11.89
Alumina .....	.34
Magnetic oxide of iron	87.00
Lime .....	.20
Magnesia .....	.80
Titanium	none
Phosphorus .....	.056
Sulphur	trace
	100.246
Metallic iron	63.07

From S. E. $\frac{1}{4}$ sec. 30, 62-10. (Transported masses in gabbro).

(By C. F. Sidener.)

Silica	11.39
Alumina	traces
Mag. oxide of iron	85.55
Titanium	none
Lime .....	.22
Magnesia	3.44
Phosphorus .....	.02
Sulphur	trace
	100.62
Metallic iron	61.95

From the new discovery of the Stone Iron Company S. W. $\frac{1}{4}$ sec. 18, 59-14.

(Two miles west of Mallmann's camp).

(By Rattle, Nye and Hollis, Cleveland.)

Analysis of a blended mixture of hematite and magnetite.

Peroxide of iron	78.01
Protoxide of iron	11.07
Silica	10.17
Phosphoric acid .....	.038
Manganese	trace
Alumina	trace
Lime .....	.38
Magnesia	trace
Sulphur	trace
Organic volatile matter	trace
Titanic acid	none
Total.....	99.668
Metallic iron	63.21
Phosphorus .....	.017

Several other determinations have been made of the iron in the ore of this age, and in all cases there is found in it no titanium. Such was found to be the case in samples from Secs. 30 and 31, T. 62-10, and Sec. 24, 61-12, and at several other places.

The mineral impurities are chiefly combined in the forms of quartz, olivine and hornblende, and occasionally biotite and pyrite.

Following is analysis of the jaspilitic hematite from Prairie river. This is the only place known where this ore appears in a typical form. At points further east it becomes first limonitic, as at Griffin's and Mallmann's camps, and then apparently magnetitic, as at the north shore of Gunflint lake. Indeed, it appears that the condition of the iron oxide is a matter of little importance, in considering the jaspilitic ores. When the ore is magnetic the general colors of the jaspilyte are dark, but with laminae of white quartz. When it is hematite the blood red jasper is most characteristic, and when it is limonitic there is with the limonitic streak a softened tint of gray with yellowish and greenish shades in the surrounding siliceous rock. In general, however, it appears that the magnetitic belt underlies the hematitic.

Hematite from Prairie River rapids, S. E. $\frac{1}{4}$ sec. 34., T. 56-25.

(By Prof. J. A. Dodge.)

Silica	8.25
Alumina	traces
Peroxide of iron.....	92.08
Lime.....	traces
Magnesia.....	traces
Phosphorus.....	.09
Sulphur.....	.01
Manganese.....	none
Titanium.....	none
	100.43
Metallic iron.....	64.45

Hematite from Griffin's Camp, sec. 22, 56-24.

(By Prof. J. A. Dodge.)

Chemical Series 210.

Silica, Si O ₂	3.62
Alumina, Al ₂ O ₃	trace
Ferric oxide, Fe ₂ O ₃	95.76
Lime, Ca O.....	trace
Magnesia, Mg O.....	trace
Phosphorus, P.....	.093
Sulphur, S.....	none
Manganese, Mn.....	none
	99.473
Metallic iron.....	67.03

From Sec. 20, 59-14. (Mallman's camp, on the Duluth and Iron Range R. R., now the Stone mine.)

Silica.....	3.52
Sesquioxide of iron.....	87.10
Manganese.....	trace
Lime and magnesia.....	trace
Phosphorus.....	.023
Sulphur.....	trace
Water.....	9.70
	100.343
Metallic iron.....	60.97

From N. W. quarter, Sec. 20, T. 60-12. (Works of Peter Mitchell.)

(By A. H. Chester, Clinton, N. Y.)

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Silica.....	22.22	11.37			
Alumina.....		2.84			
Lime.....	0.22	1.53			
Magnesia.....	1.61	3.33			
Manganese oxide.....		1.32			
Sulphur.....	trace	0.06			
Phosphorus.....		trace.			
Oxygen with iron.....		22.08			
		100.48			
Metallic iron.....	52.67	57.95	53.54	56.76	56.88

From the Mallmann mine. (S. ½ S. E. ¼, Sec. 11, 59-14.) Sampled by A. J. Trimble. Analyzed by John I. Souther, Hurley, Wis.

	No. 1.	No. 2.	No. 3.
Silica.....	6.08	8.47	10.86
Alumina.....	.69	1.12	1.35
Lime.....	trace	trace	trace
Magnesia.....	.09	.14	.37
Manganese oxide.....			
Sulphur.....	absent	absent	absent
Phosphorus.....	.015	.017	.016
Oxygen with iron.....			
Titanium.....	absent	absent	absent
Metallic iron.....	64.73	62.55	60.76

Of the gabbro magnetite many analyses have been made. The following will be sufficient to show the composition of this ore.

From S. E. $\frac{1}{4}$, Sec. 36, T. 65-3 W. (Iron lake).

(By R. S. Robertson, Pittsburg).

Silica.....	2.02
Alumina.....	2.68
Titanium.....	12.09
Sesqui-Chromium.....	2.40
Magnetic oxide of iron.....	80.78
Lime.....	trace
Phosphoric acid.....	.03
	<hr/>
	99.90
Metallic iron.....	58.48

From Sec. 36, 63-10.

(By C. F. Sidener.)

Silica.....	11.37
Alumina.....	1.32
Magnetic oxide of iron.....	53.33
Protoxide of iron.....	14.42
Oxide of titanium.....	16.03
Lime.....	.10
Magnesia.....	2.73
Phosphorus.....	.01
Sulphur.....	trace
	<hr/>
	99.31
Metallic iron.....	49.40

From Sec. 36, 65-3 W. (Iron lake).

(By Prof. J. A. Dodge.)

Silica.....	20.90
Alumina.....	1.75
Lime.....	trace
Magnesia.....	2.63
Titanium binoxide.....	2.23
Phosphorus.....	none
Protoxide of iron.....	2.01
Magnetic oxide of iron.....	70.29
	<hr/>
	99.81
Metallic iron.....	52.46

The iron sand on the beach (Sur. No. 126) near Beaver Bay is derived largely from the decomposition of titaniferous gabbro, as is shown by the following analysis:

Iron sand from Black beach, near Beaver Bay.

(By J. A. Dodge and C. F. Sidener).

Silica.....	65.17
Magnetic oxide of iron.....	30.06
Protoxide of iron.....	2.23
Dioxide of titanium.....	2.48
Lime.....	trace
Magnesia.....	trace
Alumina.....	trace
	<hr/>
	99.94
Metallic iron.....	23.50

Iron sand from S W. $\frac{1}{4}$, Sec. 33, 61-12. (South shore of Birch lake.)

(By Prof. J. A. Dodge.)

Silica	5.19
Alumina.....	2.95
Lime.....	trace
Magnesia.....	0.35
Phosphorus.....	none
Titanium dioxide.....	36.77
Metallic iron	41.12

The use of titanic ores. The present disqualification of titanic ore for use in making iron keeps these deposits in comparative disrepute. There is no mining of them now going on in Minnesota. The percentage of titanium, even when small, is considered fatal to any effort to introduce them into the furnaces of the country. A low percentage of titanium, however, (three or four per cent), if it could be maintained at a low stage, should not debar these ores from present use, and it probably would not if there were not so large and ready a supply of non-titanic ore. We may safely predict that at some time in the future these titanic deposits will be found useful and valuable.

The difficulty that has to be met in the use of titanic ore pertains not to its low grade in iron, nor the presence of phosphorus or sulphur, but to the chemistry of its metallurgy, by which a considerable amount of the iron is lost in the slag, and by which the throat of the furnace becomes sooner obstructed with refractory accumulations. Titanic ore makes a superior iron, the small amount of titanium that remains in the product giving the iron greater hardness and firmness, enabling it to stand greater wear. The iron is also well adapted for making steel. The loss that is occasioned by the smelting of titanic ores, is due to the fact that the "only solvents of titanic iron are the double silicates of *iron* and lime, or *iron* and alumina and lime, or *iron*, potash and lime, etc," and as these constitute a part of the slag that runs from the furnace, they carry away a percentage of the iron, and the loss is greater in proportion to the amount of titanium it is necessary to remove.

Quite recently a process has been employed for reducing titanic iron ore which obviates the loss suffered by the common furnace process for hematite and other magnetites.

"A paper recently read before the American Chemical Society, gives some interesting facts concerning the successful smelting of iron ore containing high percentages of titanium. This element has generally been held in disrepute by American iron masters, and they have gone so far as to say that the result of their experience has been that a mixture containing a greater percentage of titanic acid

than 1.25 per cent, could not be successfully used. When present in greater quantities, titanium has a tendency to render the slag pasty, and clog the furnace with titanium deposits if it is not made by judicious treatment to pass into the slag. On this account many deposits of titaniferous iron ore have been neglected as of no value, although such ores are apt to be very free from phosphorus and are therefore especially suitable for Bessemer iron.

In Sweden and Norway, however, ores containing from five to ten per cent of titanic dioxide have been smelted alone in charcoal furnaces, others containing from fifteen to twenty per cent or more have been smelted in admixture, or even alone, and, lastly, Norway ores containing as much as forty per cent of titanic dioxide and only thirty-six per cent of iron, have been smelted by a company in England with perfect success, as far as the metallurgy of the treatment was concerned, although at considerable expense for fuel.

The successful treatment of these titaniferous ores depends entirely on the choice of fluxes to obtain a desired result. Certain natural compounds of titanium, such as sphene, calcium silico-titanate and keilhauite, are perfectly fusible in a blast furnace, and the composition of the slag run from the furnace should be made to approximate in composition these natural compounds. The following is the analysis of ore which has thus been successfully smelted in a Norway ilmenite.

Titanic acid, 39.20 per cent.; ferric oxide, 18.59 per cent.; ferrous oxide, 30.00 per cent.; alumina, 2.89 per cent.; manganese oxide, 0.60 per cent.; silica, 5.70 per cent.; loss 0.22 per cent.; iron, 36.3 per cent.

The following was the composition of the slag, compared with natural sphene:

	Slag.	Average sphene.
Silica.....	27.83.....	31.78
Titanic acid.....	36.18.....	40.00
Lime.....	24.36.....	24.59
Oxide of iron.....	1.86.....	2.00
Alumina.....	9.18.....	2.00
Magnesia.....	0.60.....	2.00

All the titanic acid of the ore has been made to pass into the slag, excepting the small percentage left in the pig metal, perhaps one or two per cent.*

When it is considered that within the Mesabi range of Minnesota there are enormous amounts of titaniferous iron ore which have been ignored in the rush for the non-titaniferous, and that with the exception of the Adirondack region of New York, no other so

*The Engineering and Mining Journal. New York, July 5, 1890.

large deposits of such ore are now known in the United States, it is reasonable to expect that, in the light of the foregoing description of a new process, the iron industry of the state will long enjoy a flourishing condition.

Origin of the Taconic ores. The reader who has pursued the foregoing descriptions will probably have discovered that we regard the ores of the Taconic, so far as they promise economic results of importance in Minnesota, as having two different methods of genesis; also that there is reason to look for the discovery of ore deposits in Minnesota of still another method of genesis.* We see no reason to exempt the Taconic ores from those methods and principles that we have found obtained in Keewatin time. We see on the other hand only evidence to convince us that the Taconic ores date from the origin of the rocks themselves, and that the conditions that governed the origin of the rocks were but a modification of those that governed the accumulation of the Keewatin rocks. Those modifications consist in a considerable abatement of the volcanic forces and ejections, and the presence of organic matter. Chemical reactions took place under the same changes in the oceanic waters as before. Chemical silica was precipitated and was alternately, or confusedly, interstratified with precipitated iron oxide, forming jaspilitic masses and strata. These were covered by materials accumulated by more common methods of sedimentation, but were often also buried under materials that were of almost immediate eruptive nature. The Pewabic quartzite in its coarser parts, is not made up of chalcedonic silica, but in its finer portions it is almost wholly of chalcedonic silica. Whether its coarser parts were at first coarsely fragmental, and comparable to the St. Peter sandstone, as is probable, or were finely granular in the manner of the silica of the jaspilyte, we are not prepared to judge. We find it a compact, almost vitreous, though granular, quartzite, and through it run, in the vicinity of the gabbroitic beds, hornblende crystals and coarsely crystalline lumps of basic minerals that certainly are of secondary origin. In the presence of such changes, and of such an agent of metamorphism as the gabbro overflow we may infer that, whatever the condition of the pure silica at first, it has been largely changed and consolidated.† But that the iron that is involved with it was coeval in origin with the quartz itself

*Since this was written, there have been two discoveries of iron ore in the Mesabi range which illustrate in the same manner, apparently, as the ore of the Penokee-Gogebic range, the third method of genesis referred to: viz. the ore at the New Mallmann mine and that of the Merritt Brothers. These are situated in towns 59-14 and 58-18, and are described in other places in this bulletin.

†Mr. E. D. Ingall (Annual report, Can. Geol. Sur. 1887-8, p. 81 H) thus describes these siliceous fragmental rocks: "They are seen to have been fragmentary rocks consist-

there is no question. Therefore we place in one category,—viz., *chemical oceanic precipitation*—the quartzose-hornblende (or olivine) magnetite ores and the impure-jaspilitic hematite (or limonite) ores.

It is still quite possible that the magnetite which is found disseminated through the Pewabic quartzite, especially in its more coarsely granular parts, may be assigned to oceanic fragmental accumulation. This seems the more probable from the fact that the quartzite grains themselves appear to have had that origin in part.

The gabbro magnetic ore we consider an integral part of the eruptive gabbro. Its intimate association with the minerals that constitute the rock, when it exists in large masses, and its almost universal dissemination in crystalline form, and in various degrees of abundance, throughout the gabbro sheet from Duluth to Pigeon point, will admit of no other hypothesis.

That the Taconic in Minnesota was an age of animal life in the ocean is indicated not only by the carbonaceous character of the black slates, and by the recent discovery of traces of fossils in the Thunder Bay region, but also by the presence of considerable beds of the carbonates of lime, magnesia and iron.* These have long been known. They were described briefly by Logan and by Bell. That they are a portion of the original rock strata, and that their origin dates from the origination of the Taconic as a formation, it seems to us can hardly be questioned. They appear to be due to the chemical precipitation of the salts of lime, magnesia and iron in presence of an excess of carbonic acid. The curious mixture of lumps and somewhat angular pieces of chert, jasper and jaspilite in these beds, when the beds themselves are not purely sedimentary products, may be referred to the same causes as operated in the breaking up of siliceous strata in Keewatin time, and their quick transportation to new places and their burial under freshly

ing of rounded and subangular fragments which have been subsequently changed very much by the deposition of infiltration products around their constituent particles, this action having gone so far, sometimes, as to change the particles themselves and almost entirely obliterate them." We wish to dissent, however, from his explanation of the occurrence of the dolomitic beds in the Taconic, and especially from his idea of the origin of breccias (p. 83, H), which he states in these words: "The crystallizing power of the carbonates has broken these portions into fragments which have thus got distributed through the mass in such a manner as to form breccias, etc," and from the whole idea of secondary "silicification" and "dolomitization," which he adopts, apparently, from the writings of the late Prof. R. D. Irving.

*Messrs. Rattle, Nye and Hollis report a trace of volatile organic matter discovered by analysis in the magnetic ore of the Taconic from the recent discovery on Sec. 18, 59-14.

accumulated deposits of the ocean, whether of ordinary sedimentation, chemical precipitation or volcanic eruption.

We are quite ready at this time to adopt the theory that has been referred to, originating with Dr. Edward Hitchcock, and more recently adopted by Prof. J. D. Dana and Prof. R. D. Irving, that these carbonated beds may be changed, and have been, on a large scale in the Taconic rocks of New England and of the Penokee-Gogebic range, by infiltrating waters, that their alkaline constituent has been carried away and their iron has been redeposited or concentrated in a residual condition as ferric oxides, and that by this concentration large beds of iron ore have been formed. It is because of this that we state our belief that possibly important beds of limonite or hematite, originating in this way, may yet be found in the Taconic region of Minnesota, the parallel of those that have recently been opened up in northern Wisconsin. While we give assent to this theory we desire to say, still, that we have not sufficiently studied the facts in the field on which it is based in Wisconsin, to warrant us in having an independent opinion,† and that our acceptance is based on the descriptions of Messrs. Irving and Van Hise. We do not believe, however, that the process of concentration of the iron, was preceded, nor accompanied, nor followed by any such process of "silicification" as Prof. Irving urged. We believe the chert and jasper, mixed with the "cherty carbonates," were indigenous, and were the result of chemical precipitation from the waters of the Taconic ocean. "The beds and masses of chert, flint, hornstone and many jaspers, have all apparently been deposited from aqueous solutions." (Hunt in Geol. of Canada, 1863, p. 574.)

(f) Probable parallels of the Taconic ores in other parts of the United States.

There is no question in our minds as to the correctness of the parallelization which Prof. A. H. Chester adopted. He called attention pointedly to the similarity of the rocks and general geology of the Mesabi and the Penokee ranges.*

In all respects except the nearly horizontal bedding, the Mesabi district is precisely similar to the Penokee region of Wisconsin, and a person familiar with the latter cannot fail to notice the close resemblance. Here are the same

†An obstacle to the acceptance of the theory of the origin of the Penokee-Gogebic ores as expounded by Prof. Van Hise, (Am. Jour. Sci., III, Vol. xxxvii, p. 32), has lately come to light, viz: large deposits of hematite are found in the strata below the points where they are cut by the eruptive dykes, and hence below the bottom of the trough whose existence was supposed to be necessary for their accumulation. This has been developed at the Colby mine. Unless there should prove to be a second dyke forming a second trough below the other, it is hard to see how the lower ore deposit can be accounted for on this hypothesis.

*Eleventh report of the Minnesota survey p. 159.

magnetitic quartz schists, hornblendic magnetitic schists, dark and light gray quartz-schists, arenaceous gray and white quartzites, and other similar rocks; and especially here is the same apparent substitution of quartz and magnetite for each other. The writer pointed out this resemblance in his report on the Mesabi district, presented in 1875, and is now [*i. e.* in 1880] clearly of the opinion that the iron-bearing rocks of this district bear the same relations to the Huronian series as do the rocks of the Penoque iron range in Wisconsin.

This opinion has been borne out fully by subsequent examinations, almost without exception. But there has not yet been found in the Taconic rocks of the north side of lake Superior any iron deposits that are the parallel in quality and abundance of those found on the south side. The ores that characterize these strata in Minnesota, so far as they seem to be valuable, are magnetic, and indigenous in the strata. They exist in this condition also in Wisconsin—particularly in the western portion of the Penoque range, and at Black River Falls—but they have not been brought into successful economic development. The Taconic gabbro ore (titanic magnetite) is peculiar to Minnesota, so far as known, in the northwest.

In Michigan there is strong probability that the Taconic changed ores exist at Negaunee in intimate association with the Keewatin ores, overlying the Keewatin strata unconformably. We would refer specially to the mines situated in the eastern environs of Negaunee, the Buffalo, Sam Mitchell, Queen, Boston and Iron Cliff, as the most probable representatives of the Taconic ores of Minnesota, the Jackson mine being undoubtedly in the Keewatin.* At Ishpeming we think also that the Taconic exists, and that it supplies the ore taken from the principal mines. The Taconic strata here seem to be unconformable on the Keewatin (the so called diorite) and also unconformably overlaid by a great quartzite and conglomerate formation. (Compare the 17th and 18th reports).

In the area of the original Huronian are no active iron mines but some important known iron ore deposits which are presumably in the Taconic.† Owing, however, to the probable confusion of two unconformable formations under the term Huronian by the later Canadian geological reports, it is impossible to form a reliable opinion of the age of any of these ore deposits. The descriptions of some of them seem to indicate that they are in the Keewatin, in-

*Prof. Chester seems to have found on the Mesabi range a similar proximity of Keewatin jaspilite ore to magnetic ore of the Taconic--Minnesota eleventh annual report, p. 156.

†See the Seventeenth annual report, Minnesota survey, for reasons for placing the Huronian on the geological horizon of the Taconic. See also *American Geologist*, vol. vi., p. 360, "Recent Observations on Some Canadian Rocks," A. Winchell.

stead of the Taconic, and this is specially true of that on the N. W. portion of the Wallace mining location, which is apparently embraced in the Missisaugui quartzite. (Compare the 18th Minnesota report.)

Still further east, the so-called anorthosite rocks of the Canadian geologists, containing large quantities of titaniferous iron ore, placed by them at first in the Laurentian, are unquestionably the parallels of the Minnesota gabbro belt with its associated syenites and schists. In Minnesota this eruptive is not so complicated with the rocks that it invaded that it cannot be studied satisfactorily and its age has been found to be that of the Pewabic quartzite, the base of the Animike. This ore occurs in Canada at Bay St. Paul, at St. Jerome and Rawdon, and other places.

In northern New York, titanic iron ore is found associated with the "Hypersthene rock" of Emmons, and it has been extensively mined. This "Hypersthene rock" is the exact mineralogical parallel of the "anorthosite rocks," as well as of the gabbro rocks of the Mesabi range of Minnesota. Even the iron ores that it furnishes are titanic. Mr. E. Coste, of the Canadian geological survey, having studied the Archean apatite deposits has recently come to the conclusion that they are also of eruptive origin. These are found in the same mines with the magnetic ores, and he infers that they are eruptive.* This conclusion may be correct for the Labradorian (anorthosite) Archean, in which the magnetic ore is apparently always titaniferous, and which is really of primordial age; but the non-titaniferous magnetites of the Archean of Canada, New York, New Jersey and Pennsylvania are plainly interstratified and of sedimentary origin structurally, although their enclosing rocks may have been derived from sediments that were of eruptive origin.

The report of Mr. C. E. Hall on the magnetic ores of New York† is a valuable contribution to the literature of the iron ores of the country. It indicates the presence of a great quartzite, iron-bearing, formation, producing "sulphur ores", overlain by a crystalline limestone, and higher still by the "upper Laurentian" with its titanic ores. This brief report describes the limestone as unquestionably unconformable on the lower Laurentian. Judging from our studies in Minnesota we are inclined to believe that in northeastern New York will be found the eastern representatives of all the iron-bearing formations of the northwest, with the possible exception of the characteristic Keewatin with its jaspery hematites. We cannot forbear to suggest that the quartzite that bears the "sul-

*Geol. Sur. Can., annual report, 1887-88, part S., pp. 62-64.

† Report of the State Geologist of New York for 1883, p. 23.

phur ores" is the Pewabic quartzite of Minnesota, the unconformable limestone is the cherty carbonate horizon of the northwest and that the titanitic magnetites are the gabbro titanitic ores of the Mesabi range. It seems that the normal condition of the Taconic limestones is better preserved as limestones when they have been greatly disturbed by upheaval, and subjected to complete crystallization. At least in Minnesota and in northern New York they do not yet appear to have been converted to ferric oxides on any important scale, comparable to the change they have suffered in the Penokee-Gogebic range.

Further south, however, in eastern New York, the carbonated strata of the Taconic seem to continue and to have been the cause of much of the iron industry in several counties. It is true that Prof. Dana, and more recently Prof. J. P. Kimball* have assigned these ores to the Hudson River epoch, but we think that such a conclusion is not beyond doubt. There is no question that in New England, and even in the Taconic region, there is a primordial limestone immediately overlying a primordial quartzite. Such is reported by Mr. C. D. Walcott. If it is what we suppose it to be it is the equivalent of the limestones that we have found in Minnesota, and Irving and VanHise in Wisconsin, converted more or less to manganesic hematites and limonites, and hence the representative of our "cherty carbonates." Indeed Prof. R. D. Irving made pointed reference to these sideritic ores in comparison with the Penokee-Gogebic ores, when he adopted finally the theory of their origin from carbonates.† The objection to their being of Taconic age is their supposed parallelism with some limestones in which Cambrian (i. e. Trenton) fossils have been found. But so far as we can find out there is no instance of Cambrian (Trenton) fossils being found in the limestone with which the ore is immediately associated. The ore belt is represented in Vermont as lying immediately above the "granular quartz" just on the western foothills of the Green mountains, in a limestone which would necessarily pass below the Taconic mountains. This limestone occupies the same stratigraphic position further south, throughout its extent. Prof. Dwight states that "the *Olenellus* quartzite and the *Olenellus* limestone rest upon the gneiss of Stissing mountain." (Am. Jour. Sci. (3), XXXVIII, 140.) This is the limestone which is represented on the map of the geology of Dutchess county by Prof. Dana as extending to Copake where it sustains

*Am. Jour. Science, (3), XIV., 132; and (3), XL, 155.

†Am. Jour. Science, (3), XXXII, 270. Prior to Irving Prof. J. D. Dana and Dr. Edward Hitchcock had arrived at the same conclusion as to the Hudson valley siderites. Geology of Vermont. Vol. 1, p. 236.

the Copake Iron Works, (*Am. Jour. Sci.* (3), xvii, 379), and which in his descriptions he has considered an extension of the Wappinger Valley limestone in which Prof. Dwight has found Trenton fossils east from Poughkeepsie. According to Prof. Dwight's description these two limestones can hardly be distinguished lithologically, but they occur in closely related regions and almost in contiguity, confusedly faulted and abutting now against the Hudson River shales and now against the primordial. Fossils being abundant in one and very scarce in the other there is a natural disposition on the part of the field geologist to follow the guidance of the last discovered fossils as far as he can, or until some other evidence takes its place or contradicts it. In this way, perhaps, the influence of the Cambrian (Trenton) fossils has had too wide an application. This would be still more natural in the hands of an observer who entered the field with a predisposed mind toward the exclusion of all Taconic strata from the Taconic region. It is not too much to say, therefore, that while there has been a disposition on the part of geologists to follow the conclusions of those who have worked on the Taconic area and especially Prof. Dana, even to the cancellation of primordial strata in the Taconic area, there has been an evident inclination on the part of Prof. Dana and his colleagues to augment the evidence unfavorable for the Taconic and to neglect that which might be favorable. At any rate, for the purposes of this paper it will be justifiable to follow the general evidences of parallelism that exist between the eastern and western Taconic, and to call attention to the ores of western New England as the equivalents of the Mesabi and the Penokee-Gogebic ores of the northwest. The belt of limonitic iron mines of western New England passes further south, into eastern New York, thence into New Jersey and Pennsylvania where it is well known. Indeed it becomes one of the characteristic features of the Appalachian range of mountains through Virginia and into northern Georgia; and inferentially therefore we are obliged to extend the Taconic strata along the Appalachian mountains across the eastern portion of the United States.

[See Appendices B and C for a further discussion of the eastern parallels of the Taconic ores.]

(4). THE LIMONITES OF THE CRETACEOUS.

The first mention of iron ore belonging to the age of the Cretaceous in Minnesota was that of B. F. Shumard,* although he simply mentioned the existence of "nodules of oxide of iron and argillaceous iron ore," having a thickness of two feet, and thought it might prove to be extensive and readily accessible. This was in the valley of the Le Sueur river. He did not refer it to the Cretaceous age. In 1873 the Minnesota survey was carried over the same region and some further notes were made on its manner of occurrence. (Second annual report, pp. 133, 179, 203). The same ore was noted later overlying the Galena limestone in Fillmore county†, and associated with Cretaceous deposits. The discovery was made by C. C. Temple in digging a well near his (Cretaceous) sand pit, and the interesting description by him is essentially as follows:

He testifies that this bed of iron ore is at least thirty-six feet in thickness. In his well, which is six feet in diameter, and circular at the top, he dug down about eighteen feet when he reached rock, fragments thrown out revealing the Galena limestone. He describes the rock as occupying about one-half the diameter of the shaft he was digging, which afforded great quantities of soft limonite or ochre. He drilled into the iron a depth of thirty-six feet. A number of wells in the vicinity of Etna, a few miles further southeast, also struck a similar iron ore, and in other places in the same county considerable pieces of spongy limonite (not bog ore) have been found in the fields, having been discovered by plowing.

Traces of apparently the same limonitic deposit, occupying about the same position with respect to known or hypothetical patches of Cretaceous, have been met with in several counties further east. Curious nodules of limonite, apparently pseudomorphous after marcasite, are found lying loosely on the tops of the wind-worn bluffs along the Mississippi river, among fragments of siliceous rock and of quartz. Sometimes it is in coxcomb aggregations, and sometimes irregularly spreading and hepatic in outline, or botryoidal or mammillated. Such limonitic debris is also found at the Cretaceous locality in Goodhue county, about eighteen miles west of the Mississippi, where clay for pottery is obtained, and on the

*Owen's report on Wisconsin, Iowa, and Minnesota, p. 487.

†Fourth annual report, p. 58.

weathered bluffs of the same county further east. It has come to be recognized as one of the evidences of the former extension of the Cretaceous strata further east over areas where they do not now exist. Limonitic nodules and fragments of crusts occur in the blue-clay drift in all places where the presence of the underlying Cretaceous is known. They are often mingled, as at Lime Springs, Iowa, with pieces of Cretaceous shale, and even, sometimes, with determinable Cretaceous fossils. These evidences of the Cretaceous have been found in Winona, Wabasha, Goodhue and Dakota counties, and they imply that the Cretaceous must have once stretched across the Mississippi valley into Wisconsin.

It happens that in western Wisconsin much larger deposits of this limonitic ore have been found than in Minnesota. It has been considerably worked. In the Wisconsin geological reports it has occupied an important place in the discussion of the ores of that state. It appears to be found there in extensive masses lying on the slopes that descend from the bluffs, sometimes capped by the Lower Magnesian limestone, to the adjoining valleys, and is described as belonging to the underlying sandstone.* In other cases, as learned more lately, it lies on the flat tops of the bluffs, directly upon the Lower Magnesian. In the latter position it has been exploited and considerably used to mix with the lake Superior hematites at the furnace at Black River Falls, Wisconsin. It is noticeably abundant at Hersey or Woodville, and extends to Knapp, a distance of 8 or 10 miles. It has from forty to fifty per cent of metallic iron, fifteen to twenty of silica, and generally over one tenth of one per cent of phosphorus, and fluxes easily.

In Minnesota this ore is not of great value, so far as known, nor indeed is it in Wisconsin, in comparison with the ores of the crystalline rocks. Its chief interest consists in its relation to the Cretaceous. It is found making a layer separating the Cretaceous from the underlying formation, whether the lower rock be Lower Magnesian limestone, St. Croix sandstone, or the Galena limestone. Its age is therefore not determined by the underlying stratigraphy, but by the overlying, and as already stated, it indicates a former great development of the Cretaceous further east than the state of Minnesota.†

This ore in Minnesota seems to have existed at first largely or entirely in the form of a sulphide, and to have been changed by slow degrees to oxide. Such is the fact also in Wisconsin accord-

*Geology of Wisconsin, vol. iv, (1882,) pp. 54--56; 378.

†Attention was called in the first annual report of the Minnesota survey (p. 110), to lignites and green and blue shales in the Grand Traverse region, state of Michigan, that are probably of Cretaceous age.

ing to the descriptions of professors Strong and Chamberlin. This is exactly in keeping with a peculiarity of the Cretaceous clays that appertain to the Fort Benton group. Crystals of pyrite are frequently disseminated through them. The debris of the disrupted Cretaceous is so plentiful sometimes in the drift clays in Minnesota, carrying with it this sulphide, that not only are its crystals preserved, but in some cases by their solution, forming sulphuric acid, a union is effected with the lime of the "Winnipeg limestone" pebbles, causing the growth of nests and plates of perfect selenite, or sulphate of lime, the magnesia of the same pebbles uniting to form the predominant characteristic of the well-known alkali of the plains, or Epsom salt. Pyrite and selenite crystals in plates and in nests are a frequent and attractive object in excavating in the drift clays in the western part of Minnesota. This original deposition of sulphide of iron has, when studied in connection with the occurrence of other metallic sulphides in the Silurian rocks, as blende and galena, a significance to which we cannot refrain from calling attention.

It is well known that in the "lead region" of southwestern Wisconsin, and in northeastern Iowa, and northwestern Illinois, the sulphide of lead, which has formerly attracted much attention as an ore of economic importance, is accompanied abundantly by pyrite and more sparsely by blende and chalcopyrite. It is plain that if the Cretaceous ocean prevailed across the Mississippi valley in the latitude of Minnesota, it must have covered it entirely further south, and hence must have covered the Silurian limestones where these sulphides exist. It has been argued by Prof. Chamberlin, that these sulphides were precipitated chemically in the Silurian ocean by the ascent of the gaseous products of organic decay from the shales of the underlying formation, i. e. from the strongly fossiliferous Hudson River rocks. The troublesome fact that these sulphide deposits occupy crevices and "gashes" that were formed, evidently, since the deposition and consolidation of the Silurian beds, can hardly be explained on that hypothesis. There seems to be more reason to suppose that they were precipitated from the Cretaceous ocean and were gathered into these crevices during Cretaceous time, after the Silurian limestones had been exposed long to atmospheric agents and eroded by numerous gorges, and so weathered that they were rendered porous and cavernous. This explanation of their origin is in keeping with the general action of the Cretaceous ocean in the deposition of abundant sulphide of iron in Minnesota. What may have been the precipitating agent, whether ascending sulphureted hydrogen, due to organic

decay, or some physical conditions that affected the chemical solutions in the Cretaceous ocean, we will not here inquire.

(5.) GEOGRAPHIC DISTRIBUTION OF THE CRYSTALLINE IRON ORES OF MINNESOTA.

The geological map which accompanies this bulletin will convey at a glance an idea of the areal distribution of the ore-bearing formations. With the exception of the Laurentian and the later strata of the Keweenawan, all the formations here represented are iron-bearing to a noteworthy degree.

Beginning with the lowest, the Vermilion rocks (the crystalline schists) enter the state from the northeast, to the west of Hunter's island. They hold magnetic ore north of Long lake, and north of White Iron lake. There is great probability that they will be found to contain other deposits of ore of the same kind. The formation widens out along the international boundary westward, but has a general strike toward the southwest. It is evidently the Vermilion that crosses the Minnesota river at Morton and Redwood Falls, although the exact manner and area of its distribution before reaching there from the northern limit of the state are largely conjectural owing to the abundant drift sheet. It is divided into two belts, that on the international boundary running southwestward from Basswood lake being the principal belt. The smaller belt is further south, and skirts along the northern edge of the granite of the Giant's range, and is possibly the same that appears on the Mississippi river at Pike Rapids in Morrison county.

The Keewatin ore follows the Keewatin formation. This comes into Minnesota from the northeast immediately to the south of the Vermilion belt and occupies the area between the two Vermilion belts. It strikes southwestward to Ely, and Tower, where the works of the Minnesota Iron company are situated about in the center of the belt. It thence soon passes under the drift and is difficult to follow. It can only be said that it acquires a more westerly course as it extends southwest. It has been identified on the upper waters of the Prairie river, and of the Little Fork and Bowstring rivers north of Winnibigoshish lake. It is not found so as to be distinguishable at any points in the valleys

of the Mississippi and Minnesota rivers, but the deep well at *Moorhead*,* in the valley of the Red river of the North, encountered a peculiar greenish, gneissic rock, immediately below the drift, which is similar to some portions of the Keewatin, and this may be taken as the only indication that has been discovered, of the direction of strike of that terrane.

The Taconic ores will be found accompanying the Animike slates and quartzites. The titanite magnetites which occur in the gabbro are of the same age. There are three phases that here should be considered. (1.) *The lower, non-titanite magnetites*, which are associated with the Pewabic quartzite, and which do not have any recognizable or important distinction from the siliceous magnetites that occur at a higher horizon, mainly preceded the outflow of the gabbro, and they are found along the southern edge of the granite range of the Giant's hills, limiting, on the north, the strike of the Animike (if the Pewabic quartzite may be included properly in the Animike) in its course from Gunflint lake to Pokegama falls. This quartzite is apparently the same as that at New Ulm, and in Cottonwood county,† in the southwestern part of the state, and appears again at Pipestone, in Pipestone county. But the most westerly point at which it promises iron ore is near Pokegama falls on the upper Mississippi. The strike from there is southwesterly, and it probably prevails largely in the region south from Winnibigoshish lake. Whether it is separated into two areas, or not, is unknown. In all places where this quartzite is known in the state it has a prevailing southeasterly dip, indicating that it extends in an unbroken sheet underneath all that part of the state lying to the southeast from its general line of strike. (2) *The titanite ores of the gabbro group*, which next succeed, have a rather wide dispersion in the northeastern part of the state, north of lake Superior. There are places where the gabbro outflow involved, and still embraces, considerable amounts of the older quartzite with its characteristic non-titanite magnetic ore, but in general the titanite ore of the gabbro is unique, and characteristic of the gabbro rocks. In general these rocks strike from Pigeon point and Gunflint lake, southwest to Duluth and nearly to Thomson, on the St. Louis river, which is the most westerly point at

*Bulletin No. 5, pp. 27-29.

†This quartzite, with its parallels, has been supposed to represent the Potsdam sandstone, of Potsdam, N. Y., but there is another series of red sandstones at the top of the Animike, forming the basal beds of the Keweenaw, which may be the true Potsdam. It is evident that a re-examination should be made of the Potsdam region, in order to ascertain whether the typical Potsdam is the equivalent of the "Granular quartz" or of the "Red sandrock."

which they have been identified. In some way they swing round the western end of lake Superior,* and appear again in northwestern Wisconsin, but they have not been reported to embrace noteworthy quantities of iron ore, except in Minnesota. (3) The *softer ores of the Taconic* occupy a higher horizon, and they seem to be associated with great quantities of red shale, and in some cases this red shale has been disintegrated, and disseminated along with the associated red ore, over large areas, staining the drift clays and giving character to the soils. This is prevalent southward from the strike of the upper Animike rocks, and it blends with a similar coloration that is due to the disintegration of the Keweenaw sands and shales. These upper gray and black slates and quartzites, constituting the Animike proper, are conspicuously developed from Pigeon point to Gunflint and Gobbemichigamma lakes, but they are lost in their southwestward extension. It was supposed, at one time, that these strata were overwhelmed by the gabbro and hid from sight, but it is now believed, as already stated in this bulletin, that they succeeded the main gabbro sheet chronologically, and should be found, if they ever existed as such, lying unconformably upon it. On the other hand, there is found, in the region where they might be expected, a volume of eruptive rocks associated with various detrital rocks, more or less of volcanic origin, which have been denominated and mapped as a part of the Keweenaw. Further west, however, approximately in the line of strike of these rocks, and beyond the most westerly known extent of the characteristic Keweenaw rocks, northwestward from Duluth, these upper Animike strata appear to be represented, and to be highly ferruginous with red shale, and with red hematite. This red shale and the associated red iron ore, with the banded jaspilite, occupy, so far as can be seen, the stratigraphic position which is occupied further east by the gabbro sheet, and it is a reasonable inference to ascribe their existence to the effect of the eruption of the gabbro and the succeeding traps upon the Taconic ocean, causing, as has been detailed in discussing the origin of the Keewatin ores, such chemical precipitation of ferric oxide as to give all the sediments an iron coloration, and occasionally a chalcedonic composition. Still further southwest the Animike strata have not been identified with certainty. They seem to turn rather abruptly toward the south, and even toward the southeast. They constitute, with the Pewabic quartzite, the overlying, north-dipping formation at the unconformity at Penokee gap,† in north-

*Gabbro was found in the Stillwater deep well. Bulletin No. 5, p. 27, foot note. It is probable that the "trap" at Taylor's Falls is nearly of the age of the gabbro.

†This has been described both as a "fault," and as an unconformity. It was visited and described by A. Winchell in 1887, 16th Minnesota report.

Generalized section from Vermilion Lake to Penokee Cap.
[Figures show altitude above the sea]



western Wisconsin, and there lie unconformably on the crystalline schists, or Vermilion series. In the county of Morrison, Minnesota, these same north-dipping slates appear on the Mississippi river, at Little Falls, overlying unconformably a series of gneissic rocks and mica schists from which they present a totally different lithology. They have been conjecturally identified with some of the drillings in deep wells still further southwest, but they afford no outcrops.

The foregoing is all that need be said respecting the geographic distribution of these ores in Minnesota. As ores they are perfectly distinct, lithologically and stratigraphically, and need not be confounded by any geologist. Their actual distribution, in consequence of the heavy covering of drift which characterizes much of the northwest, is less certainly known. The formations, however being identified at different, and often distant points, afford us a general skeleton of their shapes and dimensions. It is only to partially fill out this skeleton that has been attempted above.

GENERALIZED SECTION.

In order that the reader may form a conception of the geological relations of the formations containing the iron ores of Minnesota, a drawing is represented on plate xv showing the succession and dip of the strata from Vermilion lake southeastwardly to Penoque gap in Wisconsin. The elevations above tide are expressed in feet at various points. This generalized section is supposed to follow, from Vermilion lake, the line of the Duluth and Iron Range railroad to Two Harbors. On the south side of lake Superior the section is based on the atlas and sections of the Wisconsin Geological survey, except as to the immediate vicinity of Penoque gap, which is drawn according to observations of the Minnesota survey, differing, however, in no essential from the Wisconsin survey.

(6). COMPARISONS WITH MICHIGAN AND WISCONSIN.

The comparative annual production of the Minnesota mines and those of Wisconsin and Michigan has been stated in the first pages of this bulletin. It has also been shown, in the description of the distribution and equivalents of the Minnesota ores elsewhere, that the formations which carry the Minnesota ores, with

the exception of the gabbro and the crystalline schists, are well represented in Michigan and Wisconsin, but that the two chief iron-bearing horizons of Minnesota are not well known and distinct formations in those states. In some of the publications of the Minnesota survey attention has been called to this distinctness, even at Negaunee and Ishpeming, as well as in the Gogebic-Penokee range.* It is evident, if our conclusions are correct as to Minnesota, that there is a necessity of making careful observations on the southern side of lake Superior, in all the iron districts, in order to determine which of the iron formations the separate mines may belong to, since it will be found not only that there is a difference in the ore that the two formations produce, but that the relation of the ore to the enclosing rock is so different that it necessitates different plans and mining methods. It is our belief that much money has been wasted in diamond-drill work, as well as in underground tunneling, because of ignorance of the habit and form of these two formations, and of the normal position and relations of the ore to the country rock. All mining can be done cheapest when the superintendents and the mining captains thoroughly understand the facts and conditions of the problems that they have to solve. As to Minnesota there is not the shadow of a doubt as to the actuality and different *posé* of these two formations. We believe that by a short review in the field the stratigraphic position of all of the Michigan and Wisconsin mines can be determined and that it will be found that much of the confusion and hesitation that have been manifest, not only among geologists, but also among mine-operators, have been owing to the confounding of two distinct formations under one term, ("Huronian"). The anomalous existence of the "Animike" strata only on one side of the great synclinal valley, would no longer stand as a reproachful stumbling-block to the systematic geologist, but the stratigraphy of the great basin would be found to be a harmonious unit.

We desire at this place only to call attention concisely to some of the comparative relations of the iron ores in Minnesota with those of Michigan and Wisconsin.

It has been the practice of geologists who have written of the iron ores of Michigan and Wisconsin, to place them all in one category, assigning them to the "Huronian," and there was a tendency at first to consider the Minnesota ores as belonging to the same undefined and uncertain position. The first expression of the Minnesota survey on this point was an initial dissent from this

* Sixteenth and seventeenth annual reports.

classification. It is to be seen in the thirteenth annual report, pages 24-37, where three iron horizons are mentioned as occurring in north-eastern Minnesota, that at Tower being described as in a lower horizon than either of the others. That was in the report for 1884. The Taconic (Animike) strata, are shown by a diagram on page 22 to overlies the formation containing the mines at Tower. The nature and the wide extent of this distinction have been gradually unfolded from that time to this. The only geologists who have recognized it, are those who have worked on the Minnesota survey. Certain differences of lithology, indicating some possible difference of age in two parts of the "Huronian" were noted by Bonney in the vicinity of Sudbury, but he had no reference to the iron ore horizons. Dr. A. C. Lawson, without calling in question the old tenet that the ores of iron in the lake Superior region are all in the "Huronian," noted positive data by which he was induced to separate the typical Huronian from the schists underlying. Dr. R. D. Irving, while noticing the stratigraphic separateness of the typical Huronian and the Animike from the underlying formation (which Dr. Lawson named Keewatin) still insisted that all the iron ores belonged in the "Huronian." Prof. C. A. Van Hise, so far as he has expressed any views, appears to be of the same opinion, and all the corps of the Canadian geologists, under the lead of Dr. Selwyn, still sweep all the "schists" into the Huronian, and expressly exclude the Taconic strata, as represented in the Animike, from the Huronian formation, regarding them as "primordial," or "lower Cambrian," supposing that such a distinction of names really necessitates a distinction between the things named.

Suffice it at this place to say that we have made comparative studies both in the area of the original Huronian, in the Marquette and the Gogebic ranges, and at Black River Falls, and have availed ourselves of re-examinations at Penokee Gap in Wisconsin,* sufficient to confirm our interpretations, and that we can make the following comparative statements with confidence:

In Michigan both of the principal iron-bearing formations are exploited, viz: that which we know as Keewatin, and that which we know as Taconic. Specifically we think the Jackson mine at Negaunee is in the Keewatin, and that the new mines about a mile and a half east from Negaunee and all of the Gogebic mines are in the Taconic. No ore is yet known in Michigan that can be parallelized with that in our Vermilion series. Nor is any titanite magnetite yet known in Michigan.

* That of A. Winchell. See the sixteenth annual report. p. 191.

In Wisconsin the ores of the Penokee range are in the Taconic, and are believed to be of that phase of the Taconic ores which we have designated *carbonated iron group*. There are magnetic belts in Wisconsin, lying to the south from the Gogebic range, as yet unexploited, and comparatively unknown, whose geographic position is such as to indicate that they are in the Vermilion crystalline schists. In the Penokee range there is no doubt but the same gradual change takes place as we have noted in Minnesota, viz: a change from hematite to magnetite in passing from one end of the range to the other. The western end of the Penokee range seems to hold magnetic ore prevailingly, while in Minnesota this seems to be true of the eastern end of the Mesabi range. As to the Menominee region, we are not familiar with it, but it would appear from the published descriptions that most of the mines are in the Taconic. At Black River Falls, the characteristic features of the Taconic magnetites, pertaining to the Pewabic quartzite, are plainly seen. Much of the iron-bearing rock here, however, lies apparently in the horizon of the *impure jaspilitic hematite* horizon of Minnesota. Nothing is known in Wisconsin of any titaniferous iron ore.

It will be seen by this, and by the accompanying geological map, that Minnesota possesses not only a greater variety of iron ores, thus far known, than either of the great iron-producing States on the south side of the great lake, but also a greater territory in which iron ores may be expected to be found in merchantable quantity and quality. In the body of this report it was intimated that the Mesabi range is the northern rim and parallel of the Penokee-Gogebic range on the south side of the lake, and that it might in the future exhibit a great development comparable with that of the south side of the lake. Even before this report closes comes the first verification of this prediction. There can be no reasonable doubt that in Minnesota, about the western and north-western confines of the lake Superior basin and extending westward to the Mississippi river, there will yet be mined in the Mesabi range even greater quantities of hematite than have been taken from that marvel of mining districts, the Penokee-Gogebic range, which blazed out with such a brilliant record only a few years ago.

At the same time, the ores of the Vermilion range, belonging in the Keewatin formation, while they can be traced distinctly north-eastwardly to and beyond the Canadian boundary, a distance of over fifty miles, are also known to extend, with the strike of the Keewatin formation, south-westwardly and then westwardly, across the upper waters of the Prairie river and to the headwaters of the

Bowstring or Big Fork river. There is no known reason to exempt this belt of rocks throughout its extent from the sanguine expectations that have been put upon it in the region of Tower and Ely. It can be traced about one hundred miles, and it may supply iron ore on every mile for that distance.

(7). SYNOPTICAL REVIEW AND OUTLOOK FOR THE FUTURE.

In the foregoing discussion of the geology and distribution of the iron ores of the state we have presented the subject as it appears to us in the light of our recent investigations. As some of the results which we have reached are different from those of our predecessors it may be well, in the interest of those who do not have the time nor disposition to examine the report exhaustively, to repeat more concisely some of the principal ideas we have endeavored to teach and illustrate, and the conclusions to which we have arrived.

1. The magnetites of the Vermilion schists are of the age of the "crystalline schists," in the upper part of the Laurentian. They are variable as to their content of titanium and have their parallels in the magnetites of the Laurentian gneisses of the eastern part of the United States and in Canada.*

They are derived largely by hydro-thermal fusion and metamorphism from hematites like those of the Keewatin at Tower—the enclosing rocks in the same way having been produced from green schists and graywackes like those of the Keewatin. Being at a lower horizon they experienced this change while the overlying strata were exempted. There is always a conformable transition from the Vermilion into the Keewatin. When they show titanium they must be referred to an early eruptive origin and have their genetic representative in the titanic magnetites of the Taconic.

2. The Keewatin hematites and jaspilytes were derived from chemical precipitation in Keewatin time from the Keewatin ocean which, while essentially an ocean of hot alkaline water, was disturbed continually by volcanic action and by the acid rains that volcanoes produce. The Keewatin rocks are almost entirely at-

*In the foregoing pages no analysis of magnetite from the crystalline schists is given showing any titanium. A more recent careful analysis of a sample of this ore however gave about ten per cent of titanium.

tributable to volcanic agencies, as to the origin of their materials, but to sedimentary agencies as to their structure. The chemical origin of the jaspilite as an oceanic precipitate is inseparably connected with and proves a like origin of the hematite. These hematites, being convertible by hydro-thermal agency into magnetites, and the Keewatin rocks by the same cause to schists and gneisses, are almost unknown in the Atlantic border region, where it is to be presumed this metamorphism was greater than in the interior of the continent, and their place is hence supplied by the "Laurentian" gneisses.

There are two sets of associated minerals in the Keewatin hematites. One is original and was formed contemporaneously with the ores, and one is secondary, and was introduced at a later period of upheaval and fracture, the latter probably being that of the great Cupriferous (primordial) age. The metamorphism of these rocks took place in Archaean time. We see no evidence of any deep-seated mineralogical changes later than the eruptive epoch of the primordial.

3. The Taconic formation embraces a variety of ores—non-titanic magnetites at the bottom, jaspilitic hematites next above, soft hematites and titanitic magnetites. These are found to constitute a well marked belt extending from Pigeon river westward to the Mississippi river, although the titanitic magnetites seem to diverge from this course and to run below the St. Louis river a few miles west from Duluth. Except the titanitic magnetite of the gabbro, which is a primary constituent of the rock, and is of eruptive origin, all the ores of the Taconic seem to be of chemical origin, and all, except those referable to concentration from oxidized carbonates, to chemical precipitation in the Taconic ocean under circumstances identical with those of the precipitation of the Keewatin hematites.

4. As to the limonites which we refer to the age of the Cretaceous, and which are more important in Wisconsin than in Minnesota, we find them overlying formations of different ages, from the Galena to the St. Croix sandstones, and hence we believe their origination did not depend on any of the older formations, but on the character of the ocean which once covered a large part of the north-west. We would also suggest that, while they seem to be largely the result of change from sulphide of iron in situ, their existence may be due to sudden changes in the alkaline waters of the Cretaceous ocean brought about by submarine volcanic eruption in a manner analogous to those of Keewatin time, to which we have appealed for the origination of the early hematites.

As to the future of the iron ore industry in Minnesota, the prospect is very flattering. With the possession of a greater variety and a greater areal distribution of iron ore than any other north-western state, there may be expected, other things being equal, a correspondingly greater development. So far as we know, other things, which depend on natural conditions, are nearly equal. At the present time roads and railroads are lacking. There can be no doubt, however, that these will be supplied. The slightly greater distance from the great centers of fuel in Pennsylvania and Ohio is the only unfavorable consideration. For many years, however, charcoal can be substituted for rock coal, drawing the supply of wood from the forests with which northern Minnesota is abundantly supplied. This is the next great step that the industry should take on in Minnesota. It would obviate freightage in both directions, and the existence of pig iron, the product of charcoal furnaces in the upper Mississippi valley, in sufficient quantity, would invite and create the establishment of numerous manufactures which depend on a supply of Bessemer iron. At the present time the revenue that is derivable from the iron ores of Minnesota, except that which comes from their first production, is reaped by the manufacturers who buy them and convert them into pig iron, or into the manifold articles of civilization into which iron enters. Large quantities of the Bessemer ores of the state ought to be converted into useful articles within our own borders, but as yet we have not a single furnace for reducing them, and all the pig iron or other iron that is employed in the manufacture of iron articles is purchased from eastern furnaces.

In addition to the advantages that warrant confident expectations for the future, based on natural conditions, as enumerated above, it may be further stated that the methods of concentration of lean ores such as have lately been put into practice for low-grade magnetites in the eastern states, are applicable on a large scale in Minnesota. If there be anything noticeable above all else connected with the manner of occurrence of the basal magnetites of the Taconic, it is the abundance of low-grade and medium-grade magnetites. The magnetism is intense in these ores, and can be followed for many miles, although when carefully examined the percentage of iron is found often to be too low to warrant mining by the ordinary means. Such ores have been concentrated for several years at the Chateaugay mines at Lyon mountain, New York, in the Adirondack mountains about thirty miles west of Plattsburgh, by a method of crushing and jigging and screening, which is applicable to both hematite and magnetite ores, the object

being to separate by gravity the iron ore, which is heavy, from the lighter particles composing its gangue; 122,814 tons (long) were thus concentrated between Sept. 26, 1886 and Jan. 1, 1888, at a cost, for crushing and concentration of 34.36 cents per long ton.* This included fuel, labor, oil waste, etc., mill supplies, renewals and repairs. This process also removes some of the phosphorus, raising the grade of the ore. This method is profitably employed in connection with mines that also produce merchantable magnetite, in which the cost of mining the low-grade ore is cancelled by the ordinary operation of the mine.

The Edison magnetic separator, recently invented, has been successfully applied to the concentration of lean magnetites from Port Henry, Chateaugay, the Croton mines in Putnam county, N. Y., and others from Pennsylvania and New Jersey. This method is dependent on the magnetic quality of the ore, and consists in letting the crushed ore and gangue fall within the field of attraction of a powerful magnet which withdraws the ore from a perpendicular descent causing it to fall into a hopper or other apartment separate from that into which the non-magnetic material falls. The magnet is increased or diminished in power by regulating the wire coils which surround it. A dynamo furnishes a current of 25 or 30 amperes and 110 volts.† By this means the proportionate amount of phosphorus in the ore is reduced, that element being in the form of crystals of apatite and non-attractable, and in some cases the titanium is affected in the same manner. There are several other methods that take advantage of the natural magnetism in the ore, and some are in use at several of the mines in Sweden and others at the Croton mines in New York.

*Jour. U. S. Assoc. Charcoal Iron workers, vol. viii., p. 10.

†Methods of concentration, and the machinery required have been described recently by John Birkinbine in the Jour. U. S. Assoc. Charcoal Iron workers (1889).



PIONEERS OF THE IRON DISCOVERIES. (P. 165.)

PART II.

METHODS OF EXPLORATION AND MINING, AND DESCRIPTIONS OF THE VARIOUS MINES.

An account of the mining interests of the state, since their beginning, would not be complete without a description of the early methods of searching for ore bodies and of travel in the wild regions of the northern part of the state. Owing to the construction of railroads which will penetrate the most remote and unsettled portions of the mining districts, and, on account of the building of wagon roads in the frontier counties, these early customs will soon become entirely obsolete, and will be matters of history and of value as such. No other mining region in the United States has ever been explored and developed in precisely the same way as the iron ore districts of Minnesota. And no other region will ever be so developed, for the necessary conditions of remoteness from railroads, abundance of canoeable water in the shape of lakes and rivers, and frequent exposures of the underlying rocks with their store of iron, are to be found in no other part of the country. The folding of the earth's crust brought the ancient rocks up edgewise to the surface, and the subsequent action of the moving ice sheets of the glacial epoch scraped off the decayed debris, smoothed down the rough peaks, and left polished domes of fresh rock in their places, eroded valleys in which gathered the waters when the ice melted away and formed the countless lakes of the region, without which the explorer would be almost unable to traverse the country, but borne on the surface of which he can travel farther in a day than he could on foot or horseback.

EARLY METHODS OF EXPLORATION.

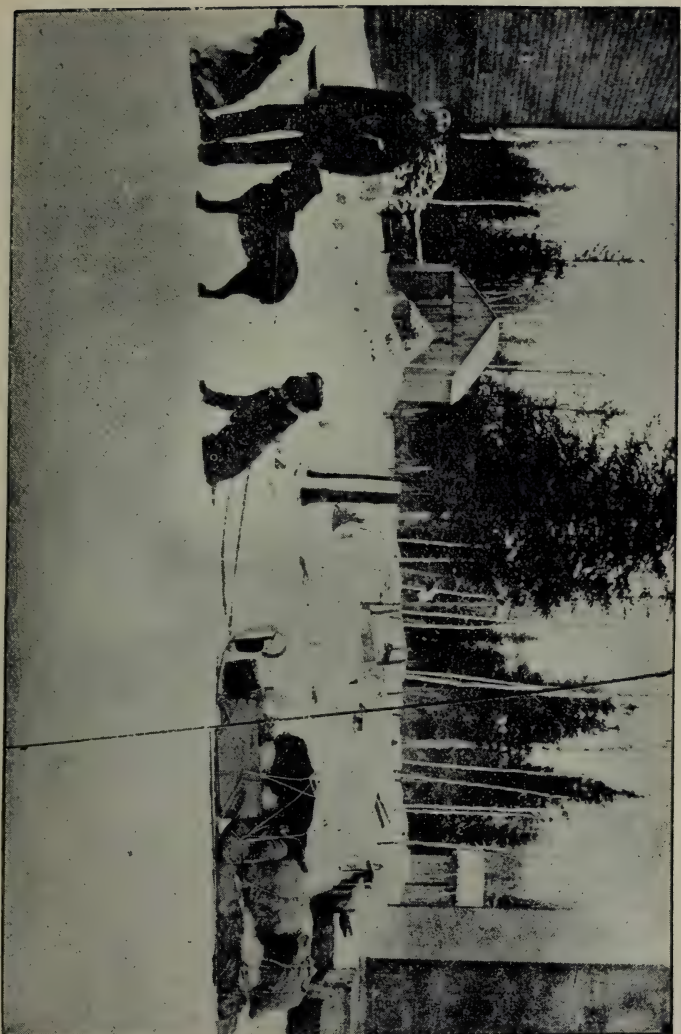
A person who to-day steps into an elegant coach on the Duluth and Iron Range railroad, complete in all its appointments, and in a few hours is safely transported along the shores of the "Big Sea Water" to Agate bay and then for the first time up over the

great Mesabi and Giant's ranges to the far-famed iron mines of Vermilion lake which are now among the wonders of the world, can have but a faint conception of the long days of labor which it required less than six years ago to make the same trip.

Before the construction of the railroad there were two ways to penetrate this wilderness and get to that inland lake, the home alike of the red man and the red iron ore; either by walking from Duluth over the old Vermilion lake "trail" which led through swamps and forests, over mountains and through gorges, or by a long and roundabout canoe-route down the north shore of lake Superior to Pigeon point or Grand Portage and then back along the course of the boundary waters. In any case an explorer who started into this wilderness was obliged to make up his mind to carry his entire outfit for many weary miles on his back, and had to prepare to meet annoyances and obstructions innumerable, from the sun which warmeth by day to the mosquito which swarmeth by night, from the storms of the lake and the wetting and ruination of all his supplies, to the cutting of trees which had fallen across his portage trail. It mattered not whether the traveler were a native Indian, an explorer for iron, a settler who wished to take up a claim and make his home there, a state geologist, or a man with the wealth of Croesus; all alike must carry their loads and tramp through the interminable swamps infested with insect pests and almost boiling under the heat of the sun. If it were winter the trip was made on snow-shoes, with dog trains to haul the toboggan loaded with the supplies and camping outfit. Here again the lakes afforded the easiest roads, and the winter trails led directly across the largest bodies of water. Plates xvi and xvii will give an idea of the earlier substitutes for railroad trains and steamboats, used since time pre-historic in Minnesota.

Both the dog-train and the canoe are of Indian origin and manufacture. It is one of the examples of the wise economy of nature that in the region where lakes and water courses are abundant, and traveling by canoe the only expedient way in the summer season, the white birch which is so well fitted for making canoes and domestic utensils should be abundant and grow of great size; while in the southern part of the state where the land is drier and more open and penetrable there are but few small birches found.

These birch canoes are the best thing that could be devised for use in this region, where the canoe first carries the traveler for a distance and the traveler then carries the canoe. They vary in length from ten to twenty-five feet, and are called one-, two- or three-man canoes, according as they will hold one or more men



ALEXANDER BAKER, STARTING FOR FORT FRANCIS. STYLE OF WINTER SUPPLY TRAIN,
1885-6. (P. 166.)



with their necessary supplies for two or three weeks. They are quite light when dry, weighing from forty to seventy-five pounds, or more. A canoe of average size is easily carried inverted on a man's head and shoulders, as represented in plate XVIII, and if the traveler is in a hurry he will take a "pack" of fifty pounds besides.

To make a birch canoe an Indian first selects a good-sized birch tree, devoid of limbs for fifteen or twenty feet above the ground. With an axe he then makes a vertical incision up one side of the tree as high as the bark is good, or as far as he desires to cut it off. The bark of a birch tree is generally about a quarter of an inch thick and is under high tension owing to the annual growth of the wood inside. In the spring the bark when cut will shrink away from the incision and will frequently peel off of its own accord for two or three inches on each side of the cut. The Indian strips off this bark in one whole piece with his axe, rolls it up and takes it home. The inside is then scraped and the outside peeled off to make it smooth and obtain the desired thickness. This large piece is for the bottom of the canoe and reaches from end to end, the inside of the bark forming the outside of the canoe. A frame-work is made of white cedar, and around this framework the bark is fitted. The ends are made pointed and the sides are enlarged by sewing pieces of bark on them. The sewing is done with an awl and the thread used is obtained from the inside of long, flexible spruce roots. The canoe is allowed to dry a short time and is lined first with thin cedar withes running lengthwise of the canoe and is then braced by transverse bows of cedar on the inside. The seams are covered neatly with pitch, and a couple of cedar paddles complete the outfit. Such a canoe will hold from three hundred to fifteen hundred pounds, will last two seasons, three with care, and in the hands of a skilful canoeman will navigate the roughest waters of lake or rapids in safety. It takes an Indian and his family three or four days to make one and they are worth from five to twenty dollars, according to the demand, the season of the year, the size and beauty of the canoe and the place of purchase, as well as the necessity or greed of the Indian owner.

Great care is sometimes taken by the Indians to have a fine dog train. Three or four dogs are secured and trained so that they will travel long distances and haul a heavy load over the snow-covered lakes. The following description of one is taken from the *Vermilion Iron Journal* of April 3, 1890:

"There arrived in this city, (Tower), late Thursday afternoon, one of the most magnificent and well-trained dog-teams it has been our fortune to see in this or any other country. There were four

of the dogs, three nearly white, the other almost black; and they were the brightest, liveliest quartette of canines that have ever yet come in from a woodman's home. The equipment, too, was far from the ordinary style. The dogs each wore a nice, ornamental collar, supplied with tiny Russian bells that tinkled merrily to their lively little trot when on the road. In addition to this, each was comfortably covered with a handsome blanket worked in fancy colors and ornamented with Indian beads. The toboggan was an exact counterpart of those used by the Esquimaux, being a frame covered by a tanned moose skin, the whole thing very much resembling a whitewashed coffin, except, perhaps, the fancy striped painting on the sides. The toboggan was water-tight and could be used for a canoe in case of an emergency. The outfit was the property of a half-breed, Richard Lyons, who brought in a man named Frank Mosher, from Fort Francis, Canada, 110 miles from Tower. The entire distance was made in twenty-two hours' travel, taking one night's rest when about midway in their journey."

Such traveling as that will grow more rare from now on, because Indians appreciate the use of a railroad train as well as anybody.

Besides a canoe in the summer months and snow-shoes in the winter, of course an explorer requires to be otherwise equipped for the business of searching for iron mines. He must be endowed both by nature and by training with qualities of patience, endurance and observation. He must be able to travel through any kind of a wilderness and not lose his way. He must be a canoeman, a packer, a cook and a geologist. He must know iron ore from trap rock, and must have a general idea of the geology of the region, so that he will not waste his time and energy and lose valuable opportunities of discovering and acquiring desirable mining properties.

Incompetent men are very often relied on to do work for which they are in no wise fitted. Several cases have been known to the writers, where wealthy capitalists and even intelligent men who are engaged in the iron industry in Ohio and Pennsylvania, have sent parties to spend the summer in searching for iron ore, which parties were in the charge of men who insisted on exploring during the whole season in a district of gneiss and crystalline schist, whereas a person acquainted in the least with the general geology of the iron ores of this state would have informed them that such search would be fruitless. The result was that they spent large sums of money and had nothing to show for it.

Outfit. It is seldom that an explorer goes alone to look for iron or timber land. The operations of camping and traveling can be much better conducted by a small party of two or three. Their

outfit should not be made any bulkier than necessary, and yet it is better to have too much than too little, for a person suffers greater inconvenience from the lack of sufficient food or clothing or blankets than from the extra exertion required to transport them.

A list of the various articles proven by experience to be of use and almost of necessity for an explorer, would include the following: For personal equipment he should have a couple of large, heavy woolen blankets, weighing eight pounds each; a canvass or rubber blanket to lay under them; a sack about the size of a seamless wheat sack, to hold his clothing; this may be made of heavy oil-cloth or of a rubber blanket, if he desires to have a change of dry clothes; a small "A tent" made of 6-ounce or 8-ounce duck. Of course this should be large enough to contain all the members of the party, and should be thick enough to keep out the rain of heavy showers in the spring. In the fall a "shed tent" is convenient, for a fire can be built in front of it for warmth, and rains are not so frequent. Sometimes a party does not need a tent for three or four weeks at a time, but can sleep under the blue canopy of the heavens with perfect comfort. In his clothes-bag the explorer puts all of his personal accoutrements and toilet articles. These should comprise extra suits of flannel underwear, flannel socks, shoes or shoe-pacs, sewing bag, flannel shirts, etc. He should have for constant daily use a suit of strong clothes through which air can circulate freely; and his foot-wear should be carefully selected. Whatever he wears on his feet should be large enough to be worn above at least two pairs of woolen socks, and it is better to wear shoes or shoe-pacs, with or without canvass leggings, than long, heavy, water-tight boots or boot-pacs. A person will be in the water several times a day, and frequently for a large part of the day, and it is easier to tramp around with a shoe full of water than a boot full; and besides, it is easier to remove a shoe and pour out the water, than to pull off water-soaked boots. A small case of common toilet articles is convenient, and two or three simple remedies for biliousness, colds and dysentery, almost a necessity. Almost anything in the way of a hat can be worn, generally, however, something which will not interfere with the operation of a "pack strap," or be knocked off easily by bushes.

In the spring of the year the explorer is apt to be greatly troubled by the insect pests, "deer flies," "black flies" and "sand flies" or "midges," ("no-see-ums") by day, and mosquitoes at all times. It is sometimes necessary to build a small "smudge" whenever a person stops to rest or make observations, and at times impossible to write notes without gloves on one's hands and a hand-

kerchief over one's neck and face or an Indian to stand by and wave a brush of branches and leaves over one's head. But such days are not very frequent and do not occur after the middle of July. Various kinds of ointments are recommended to keep off the mosquitoes, but they are generally worse than useless. A person soon becomes inured to them and his system is so inoculated with the poison that their bite ceases to produce swellings. The best way is to have the tent fringed at the bottom and up both sides of the door with half a width of "cheese cloth." This can be drawn in around the bottom and held down by hammers, specimens, blankets, etc., while the door-flap can be pinned together by clasp clothes-pins. The few mosquitoes that are in the tent can be silenced by singeing their wings in the flames of a candle, and the tired explorer can obtain the sleep that is an absolute necessity, unmindful of the hum outside which sometimes sounds like a pipe-organ at a distance.

The camping outfit should include a set of pails, pressed tindippers which fit together, frying pans with hollow handles, plates, knives, forks, spoons, and a tin baker which can be set up before the fire, and can be folded into small compass for transportation. There should be an axe or two, a medium sized geological hammer for each member of the party and a miner's pick. The most convenient method of carrying these articles, as well as the stock of supplies, is in "pack-sacks" which are made of canvass fitted with broad leather straps to go over a man's head and shoulders. With one of these contrivances a man can carry on his back a load of one hundred pounds across a portage of half a mile without resting, and when it comes to steady packing can go twice as far at one "pull."

Each member of the party, unless he be an Indian, should be supplied with a good compass with which, by the aid of plats and maps, he can find his way in any part of the region. A dip needle is frequently indispensable in regions of magnetic ore. A small shot-gun and a couple of strong trolling hooks and lines will be the means of contributing a refreshing variety to the bill of fare and lighten both the load to be carried and the bill for groceries. In the matter of provisions individual tastes may to a large extent determine what shall be taken. All things like sugar, salt, flour, etc., that would be spoiled by being wet, should be carried in bags made of oil-cloth or oiled canvass. The staple articles of food which can be taken on a trip of this sort include flour, beans, ham, salt-pork, oat-meal, rice, tea, coffee, sugar, salt, pepper, dried apples and prunelles or prunes, baking powder, pickles and dried

corn. Butter and apple-butter can be obtained and carried in wooden caddies, but canned goods are not suitable on account of their bulk and the angularity which prevents them from fitting well into the hollow of a person's back when in a pack to be transported from one lake to another. Onions are excellent preservers of health and with fresh apples should be on hand as continually as practicable. In the proper season grouse, ducks, rabbits and other larger game may frequently be shot, and the lakes are generally full of fish which will bite a troller. Blue-berries, red raspberries and strawberries are abundant and grow to remarkable size, so that a person can pick a pail-full in a short time. On the whole the bill of fare is excellent and even an Indian will get up an inviting repast in a few minutes.

On the ground. Around the shores of the numerous lakes the rock exposures are so frequent that a person can trace the outlines of the various geological formations with a fair degree of accuracy by following the shores alone. But the enterprising explorer goes everywhere; he climbs the highest hills and crosses the widest, densest swamps, for there may be an outcrop of iron ore in either place. He knocks off a corner here and digs off the moss there until he knows every foot of the ground around him. If he sees angular pieces of "float-ore" he attempts to trace them to their home and see if there is more like them. The observing prospector notices that the "float" has all come toward the south or southwest and he follows therefore toward the north or northeast, according as the glacial striæ on polished surfaces indicate that the movement of the ice-sheet was in one or the other of these directions.

A fragment of red jasper is considered as good an indication of the presence of iron ore in the vicinity as a piece of ore itself; but black jasper is regarded as a poor indication, and more than one property has been neglected because it contained or showed only black jasper associated with the ore.

If the ore is magnetic, as much of it is, the dip compass traces its boundaries and strike, and the claim is taken so as to include as much of the area where the needle stands at 90° as is possible.

Of course a prospector cannot tell very much off-hand about the exact quality of the ore which he discovers. He may be experienced enough to judge from the specific gravity as he weighs it in his hand that it contains 50 per cent. or 60 per cent. of iron; but of the presence of phosphorus or titanium or even sulphur, he can tell very little without an assay or analysis.

Diamond drill. It is seldom that the extent of an ore deposit

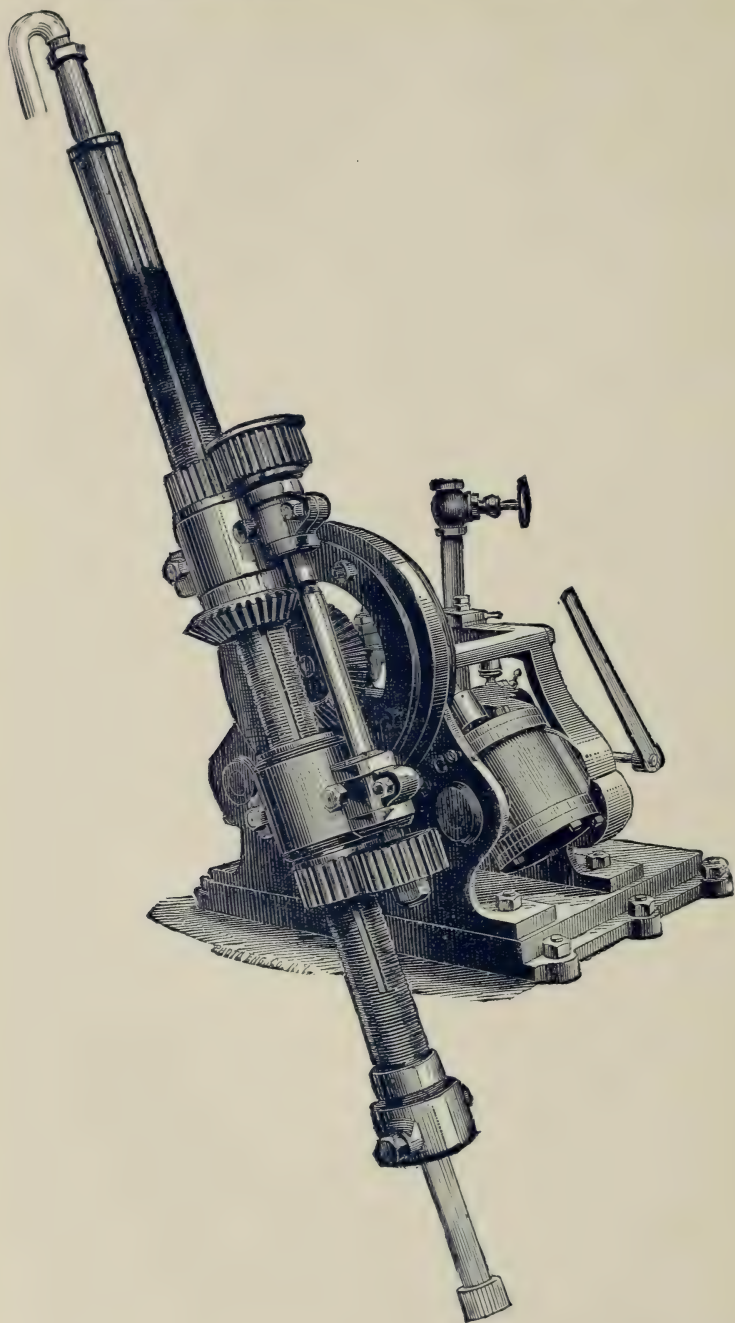
can be learned without stripping or shafting or drilling. By far the most satisfactory way to ascertain the real value and extent of an ore deposit or the exact size and locus of the ore lenses is by the diamond drill. It is rather costly at first, but is the cheapest in the end. The core which it brings up is a faithful record of the rock through which it penetrates, and with such a record there need be very little speculation or doubt about the propriety of sinking shafts and attempting to find ore. By means of it the mines which are already in full operation are continually discovering new ore lenses at various depths below the surface. These drills can be worked at any angle and to almost any required depth, and will produce a core from one to three inches in diameter. According to a letter from Mr. H. A. Wilcox, dated June 16, 1890, a diamond drill hole at Soudan was made 1,319 feet in length. It ran at an angle of 24 degrees and was drilled near the center of the "Stone" location up to about under the point where T, BB and Z holes were started, and passed through "soap rock", jaspilite, quartz, and white siliceous limestone.

The principle of the diamond drill is, *first*, the rapid rotation of a hollow "bit" of which the cutting edges are the diamonds, set in such a manner that they are the only part of the tool that comes in contact with the rock; and, *second*, a stream of water forced down through the interior of this bit, passing up outside of it and carrying away the material ground up by the diamonds.

The hollow bit is a steel thimble, having three rows of diamonds (bort or carbon) embedded therein, so that the edges of those in one row project from its face while the edges of those in the other two rows project from the outer and inner periphery respectively. The diamonds of the first mentioned row cut the path of the drill in its forward progress, while those upon the outer and inner periphery of the tool enlarge the cavity around the bit, and admit the full ingress and egress of the water. The bit is screwed to the core-barrel or spiral grooved guide, and this to the drill rods which are made of heavy lap-weld tubing, and added section after section as the hole deepens.

When the drill-rods, with bit attached, are rotated and fed forward, the bit passes into the rock, cutting an annular channel. That portion of the stone encircled by this channel is, of course, undisturbed, and the core-barrel, passing down over this, keeps it intact until the rods are withdrawn, when the solid cylinder thus formed is brought up with them, the "core-lifter" breaking it at the bottom of the hole and securely wedging it in the core-barrel.

At the upper end of the drill rods is a water swivel, connected



SHAFTING DRILL. AMERICAN DIAMOND ROCK-BORING COMPANY. (P. 173.)

with the steam pump. By means of this pump a constant stream of water is forced down through the hollow drill rod, thereby keeping the bit cool and the hole clear of sediment, which is forced by the water pressure up the outside of the rods to the surface. When a core is not required, a perforated or solid bit may be used, the detritus being washed out by the water, as when boring with the annular bit.

These general principles of boring with the diamond drill are always the same, the different machines, by slight changes, being applicable to any kind of rock drilling.

The diamonds are set by drawing the soft steel of the bit up around them, and each diamond projects exactly $\frac{1}{8}$ of an inch, so as to make the hole perfectly round and of the same size all the way. These diamonds wear off and thus sharpen themselves, and have to be reset quite frequently, sometimes every ten inches of boring, but the average is about six feet, taking hard jasper and soft schist together. One man can set three bits in a day and a bit set with diamonds is worth about \$200.00. Corundum has been tried in the place of diamonds, but it has no effect on the jasper.

The core-bar is the tube just above the bit into which the core of rock projects and in which it remains while the drill is pulled out. The longest core-bars are about ten feet, but the drill is pulled out every two or three feet to see that it is working properly.



FIG. 18. ANNU-
LAR BIT.



FIG. 19. PERFOR-
ATED BIT.

Cuts of the shafting drill manufactured by the *American Diamond Rock Boring Co.*, and of the core-bit, core-lifter, core-barrel and perforated bit are shown in plate XIX and figures 18-22. This drill is especially adapted to long-hole boring in shafts. It will bore at any angle to a depth of 500 feet, and weighs when set up 1,000 pounds. The size of the bit is $1\frac{3}{4}$ to 2 inches in diameter. In the *annular or core bit*, figure 18, the projections represent the diamonds, which constitute the cutting edges. This bit or boring head revolves at a speed of from 400 to 1,000 revolutions per minute, the size of the core bored out depending upon the inside diameter of the bit, or more exactly speaking, on the track cut by the diamonds which, it will be observed, project so that they alone come in contact with the material while drilling.



FIG. 20. SOLID
BIT.

Figures 19 and 20 are the *perforated or solid bits* which produce the ordinary hole used for blasting



FIG. 22. CORE-BARREL, OR SPIRAL-GROOVED GUIDE AND BIT.

purposes, the rock, being pulverized during the revolution of the bit. The water passes through perforations made in the steel in sufficient volume to answer the same purposes which are provided for in the annular bit. The advantages of this method of boring are that the diamonds will cut anything, the holes are perfectly cylindrical and are carried in a perfectly straight line in any desired direction.

Figure 21 is the *core-lifter*, a simple mechanical contrivance for breaking and lifting the cores which have been bored.

Figure 22 is the *core-barrel or spiral grooved guide and bit*. It consists of a wrought-iron tube, from eight to sixteen feet long, made the size of the hole to be bored and set with diamonds at intervals to prevent it from wearing. The spiral grooves are provided the full length of these tubes, to allow egress for the water and sediment on the way up to the top of the bore-hole. It is of especial value as by exactly fitting the hole bored it prevents the drill from diverging from the direction in which it started.

At the Minnesota mine at Tower there are at present six diamond drills at work summer and winter under the charge of Mr. W. H. Cole. They are each run by a portable steam engine with a boiler of ten horse power. A small Blake pump is used with each drill to furnish a continual stream of water which goes to the bottom inside the drill and comes up around the outside, bringing the abraded rock material with it. A pressure of 60 pounds is carried on a 10x12 inch hydraulic cylinder to feed the pump. The drill is pulled out in sections of 20 feet, each of which is unscrewed from the next one. These sections or joints weigh about 50 pounds apiece. The cost of drilling per foot varies from two to eight dollars and averages a little less than three. An average depth of about ten feet a day is drilled now, but the distance used to be much less three years ago.

At Tower the water used in running the diamond drills has been obtained in several instances from an artesian flow struck in drilling the holes. It issues



FIG. 21. CORE-LIFTER.



FIRST OPENING, (MALLMAN AND STUNTZ, JULY 1875.) NOW THE LEE MINE, SOUTH RIDGE. P. 175.)

from the holes drilled on the hill above Soudan. Thus at "KK" hole a good flow of water was struck at a depth of 320 feet. This water is clear and cold and has been piped to several of the buildings where it runs continually, furnishing a fine supply of pure water. It is probably water that soaks into the rock through cracks and crevices and not through some porous stratum.

It is needless to say that it is only since the advent of a railroad to this region that diamond drills could be transported and operated to any extent. There are instances, however, where a drill and steam engine have been carried 50 or 60 miles by horses and in canoes and operated at points remote from railroads. Such was the case of the work done on Chub (Akeley) lake, west of Gunflint lake. A set of boring apparatus was carried in from Grand Marais and kept at work all of one winter.

The first test-pitting and mining. Some of the early explorers, in addition to the usual light explorer's pick carried along a set of rude hand-drilling apparatus sufficient to bore a hole for blasting. The illustration on plate xx is from a photograph made in the summer of 1889, of the first blast for iron that was ever fired on the Vermilion range. It was done by John Mallmann and Geo. R. Stuntz, on the "south ridge," at a place a little east of where Tower is now located, and near the Lee mine. Mr. Mallmann has kindly given the following statement concerning the exploration:

MESABA, Sept. 27th, 1890.

Prof. N. H. Winchell:

Dear Sir.—Your inquiry of the first work done on the Vermilion iron range I received, and in reply will give you the details:

Mr. George Stuntz, John Houli and William Nana Bushue and myself started from here to Vermilion in July, 1875, and after exploring the Lee hill and the Tower hill, and Jasper peak*, we started the stripping of the ore on the east end of the Lee hill where Mr. Stuntz had first discovered the iron ore during the gold excitement in 1866. I was the only miner in the party, and Mr. Stuntz asked me to put in a blast in the ore, which was the first blast ever put in the iron ore of the Vermilion range. I had Indians striking the drills for me, and bored a hole about five feet, and threw out a mass of ore which I think you have seen. The last of August, 1875, the party started over to Birch lake, looking over the now Chandler, Pioneer, Zenith and Eaton-Merritt croppings, thence up Birch lake to the Mesabi range where Prof. Chester was making his examination.

Yours truly,

JOHN MALLMANN.

According to information from Mr. Henry Mayhew, dated Jan. 21, 1886, the earliest real effort at practically testing the rocks at Vermilion lake was made by a party in 1861, consisting of Amos

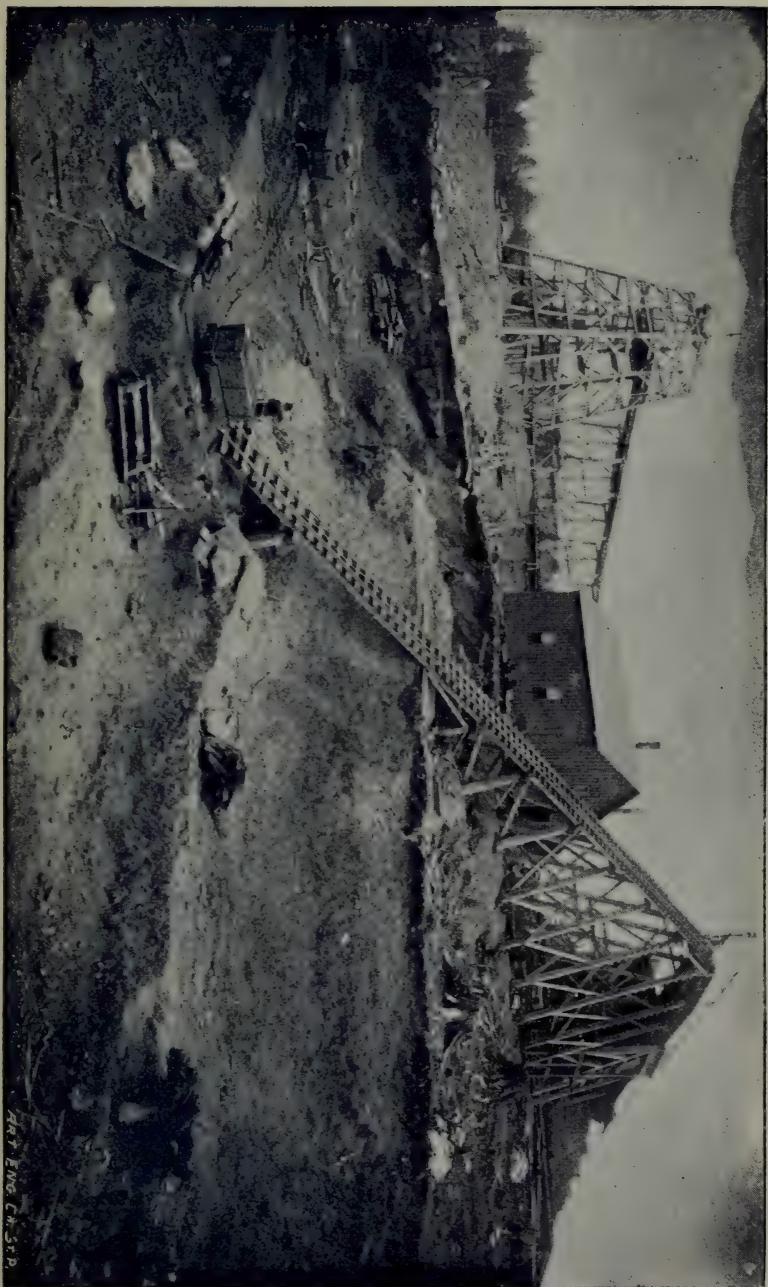
*This is sometimes called Chester peak.

Hall, of St. Paul, Mr. Ely, E. H. Johnson, of Oneota, and Henry Mayhew, who proceeded to Vermilion lake by the usual route up the St. Louis river, by canoe, in search of gold. They brought down quartz, mixed with slate, that assayed, according to the United States Mint, \$19.50 per ton in gold. Nothing more was done about this till H. H. Eames, state geologist, made his report of finding gold at Vermilion lake, and out of it grew the gold excitement of 1865 and 1866. It was, as appears from Mr. Mallmann's letter, the same year that Mr. Stuntz discovered the iron ore ridges at Tower. This discovery, according to Mr. Mayhew, "was scripped by Eames and others. We packed in some 200 lbs. of iron, and shipped to eastern iron men. It proved satisfactory, but was too far from railroads. It was then abandoned till 1868, when J. B. Culver and other parties, with George R. Stuntz, re-surveyed, and with same result, abandoned it for want of a railroad. It lay till the St. Paul and Duluth R. R. was commenced, and the present parties came to the front." This shows the origin of the museum specimens of specular hematite distributed by the Smithsonian Institution in May, 1867, prior to the examinations of Prof. Chester, to which he has referred in his report* as having been sent, with the so-called gold ores, to the Paris Exposition in 1866. These samples were evidently obtained by breaking them by sledges from the natural cropping, as we have no knowledge that any blasting was done in the iron ore in 1866, although there were, near at hand in connection with the gold mining then going on, ample facilities for procuring drills and blasting powder.

The first work of this kind in the region north of lake Superior, as is well known, was not done for the purpose of finding mines of iron, but of silver and gold. Some twenty-five years ago there was quite an excitement over reported gold discoveries in the vicinity of Vermilion lake. Parties of miners made their way to this region with large outfits prepared for mining and assaying. Shafts were sunk and drifts made into the hillsides where quartz veins were discovered. A stamp mill was erected on the stream leading from Trout lake to Vermilion lake, and a great deal of money was wasted in a nearly fruitless search for gold. The remains of these old workings are still to be seen in the piles of refuse and the shafts now filled with water, found in several places around Vermilion lake.

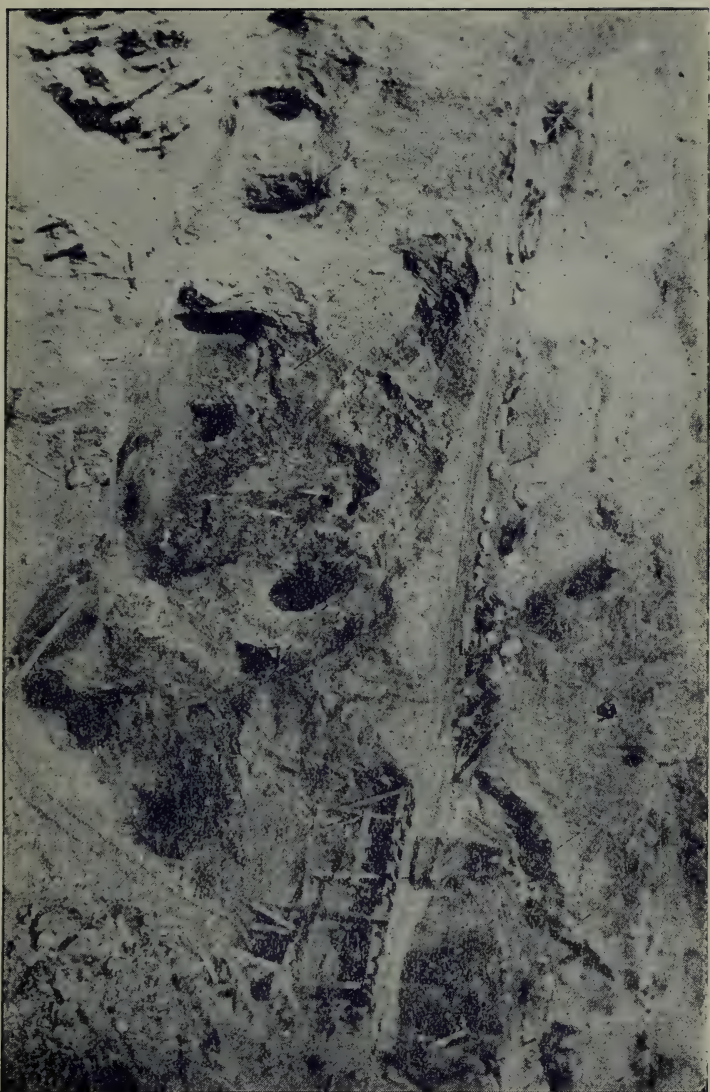
Methods at the Mines. The lenses of iron ore and jasper are harder and resist erosion longer than the schists and slates which enclose them. They were found forming large glaciated outcrops

*Eleventh Annual report, p. 150.



Met. Eng. Co. S. P.

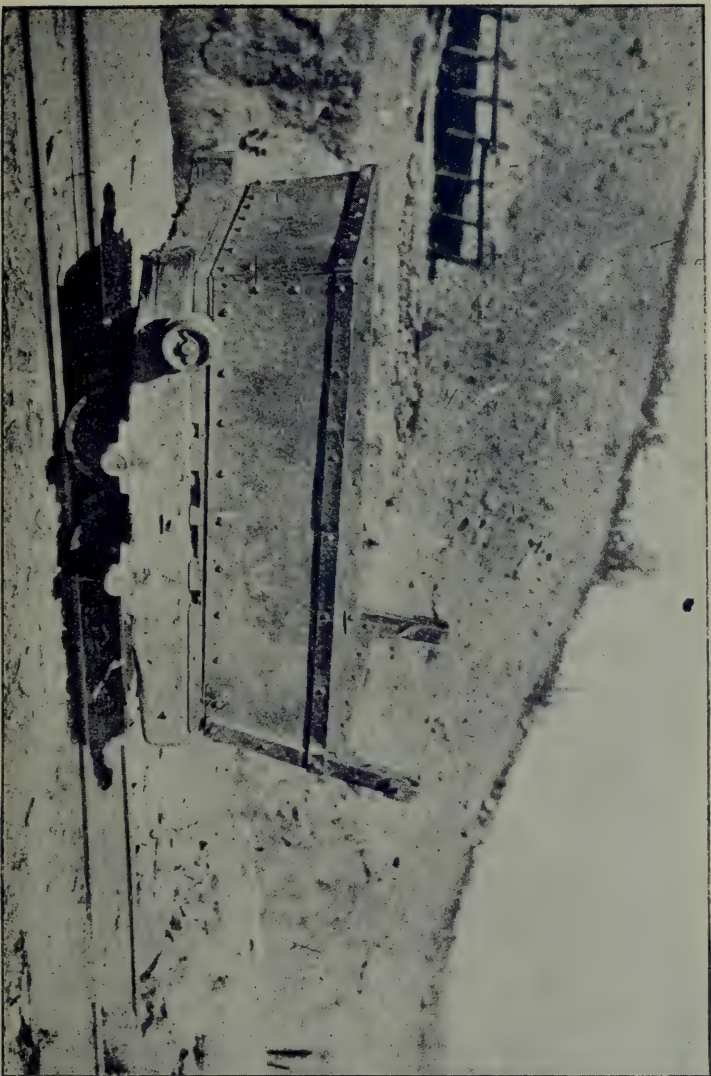
INCLINED HOIST FROM THE OPEN PIT, AND SHAFT TIMBERS FOR THE PERPENDICULAR HOIST.
CHANDLER MINE ELY. (P. 167.)



OPEN PIT OF THE CHANDLER MINE, ELY, SHOWING DRIFTS FROM WHICH
ORE IS BEING TAKEN.



CHANDLER MINE ELY. SHOWING OPEN PIT AND ENTRANCE TO UNDERGROUND WORK



SELF-DUMPING ORE CAR. TOWER.



HOISTING SHAFT, PIONEER MINE, ELY. SHOWING A LOADED CAR ON THE WAY TO THE DUMP.



P. E. CO. 374

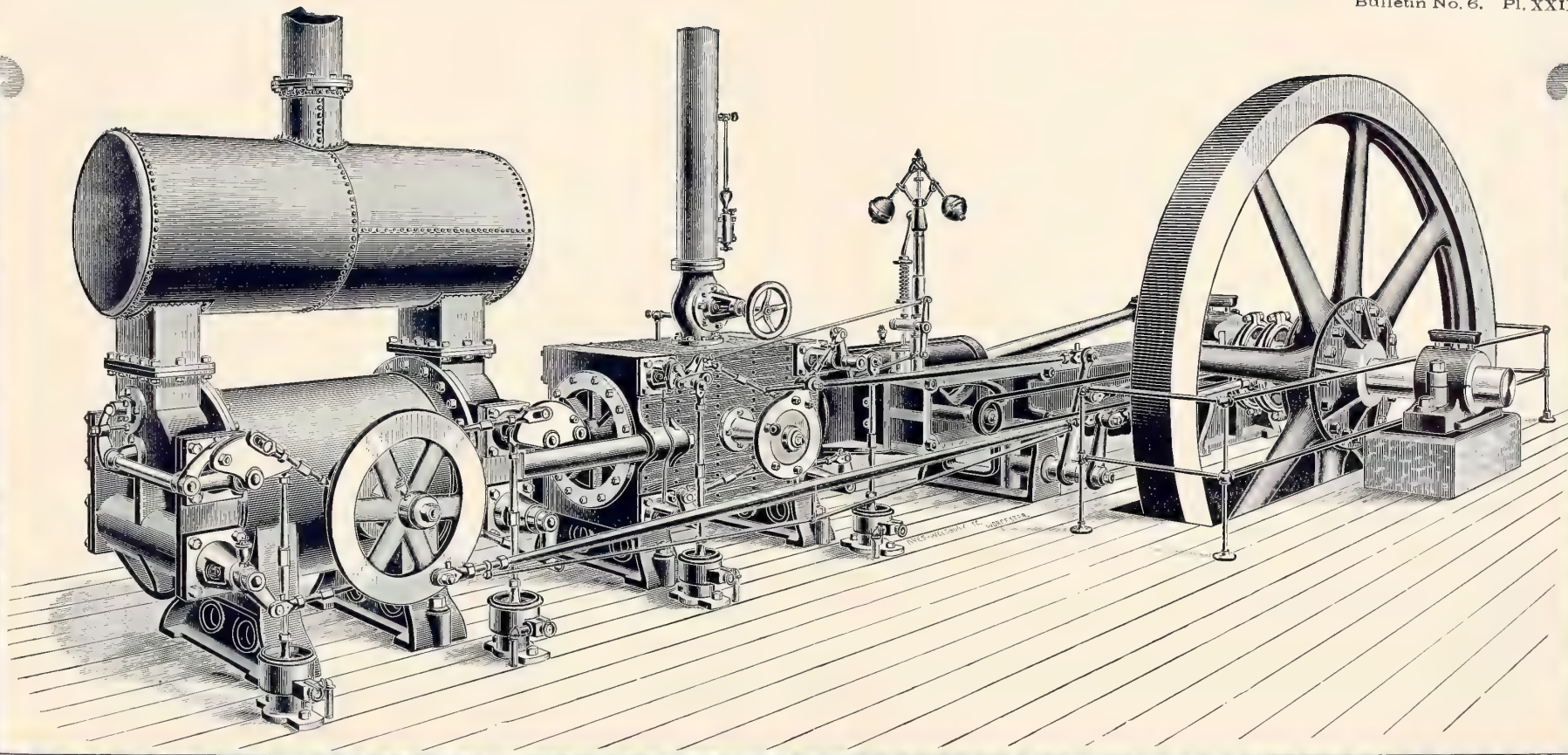
STOCK-PILES, CHANDLER MINE, ELY.



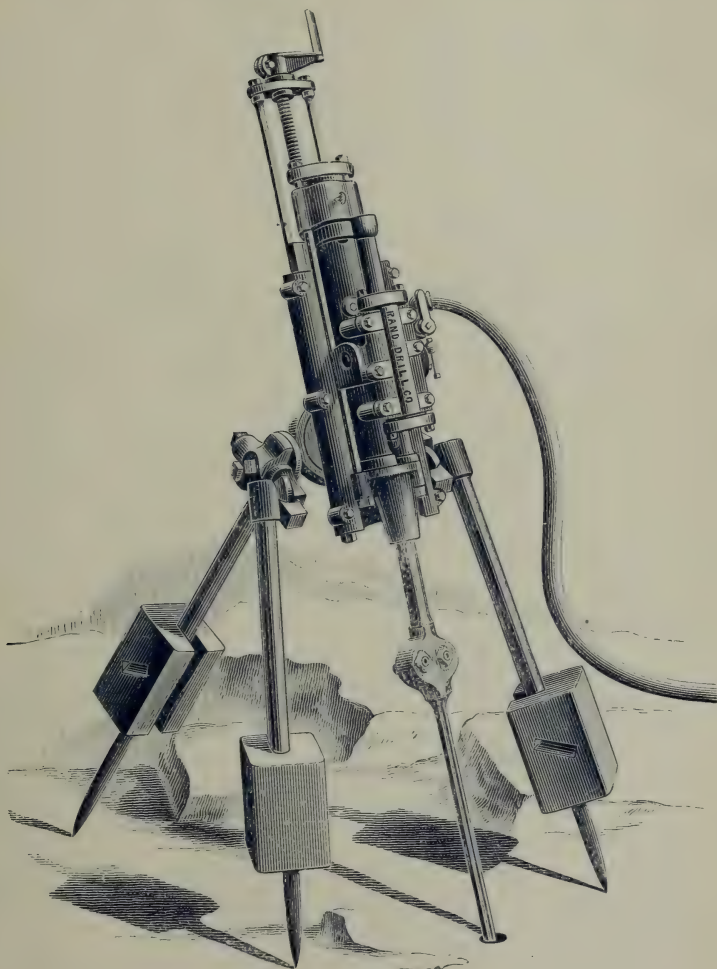
ORE-POCKET. TOWER MINE.



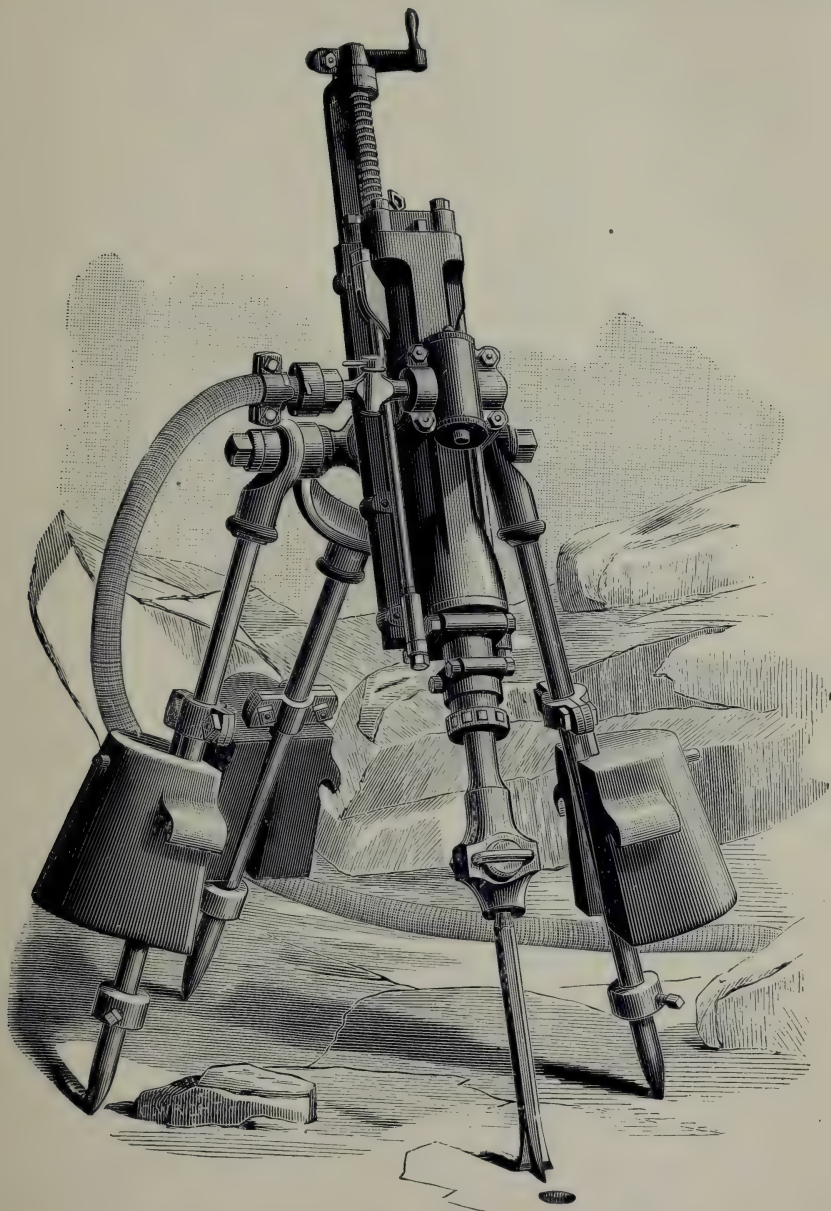
LOADING IRON ORE AT THE CHANDLER MINE, ELY. (From the pocket to the railroad car.) P. 176.



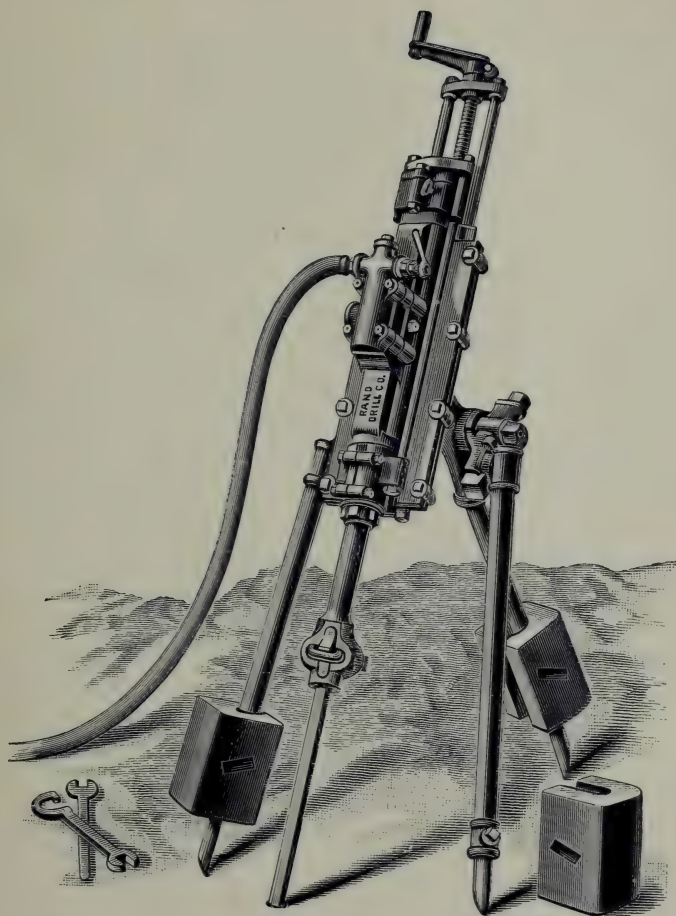
REYNOLD'S IMPROVED AIR COMPRESSOR. E. P. ALLIS & CO. P.176.



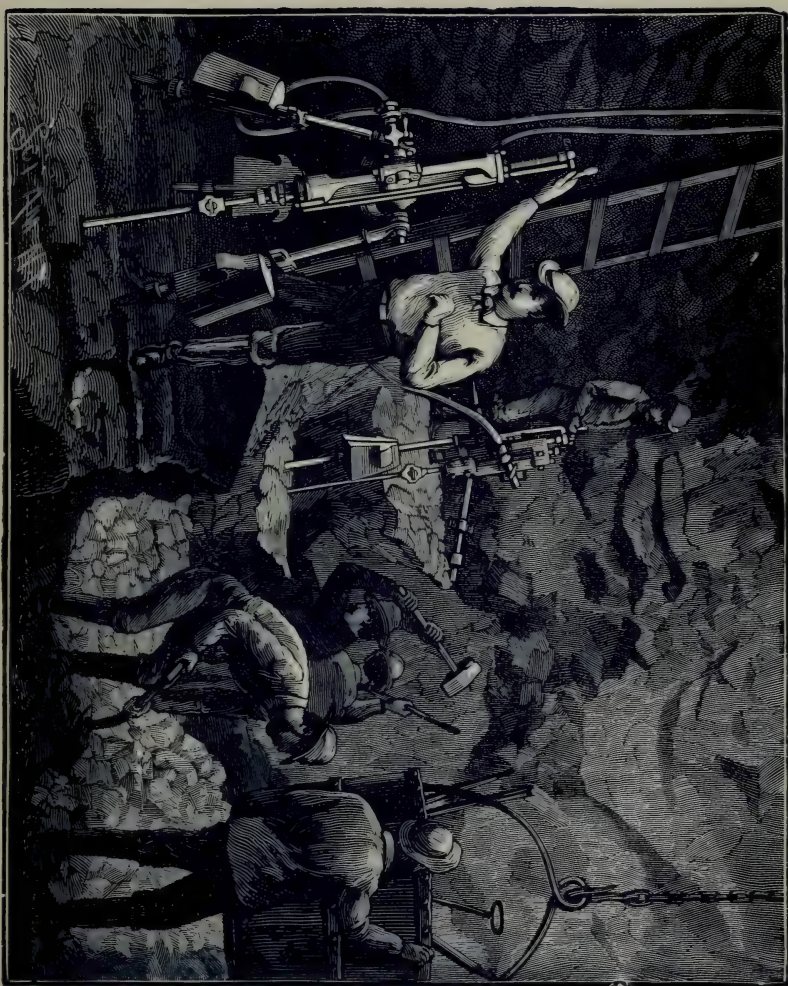
THE SLUGGER ROCK DRILL.—Rand Drill Co. P. 176.



ECLIPSE DRILL.—Ingersoll-Sergeant Co. P. 176.



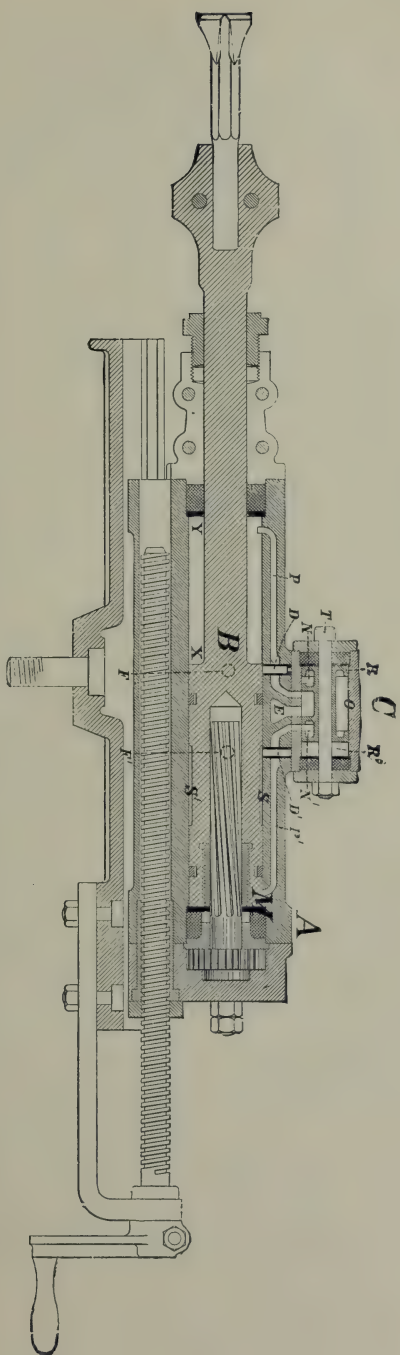
LITTLE GIANT ROCK DRILL. RAND DRILL CO. P. 176.



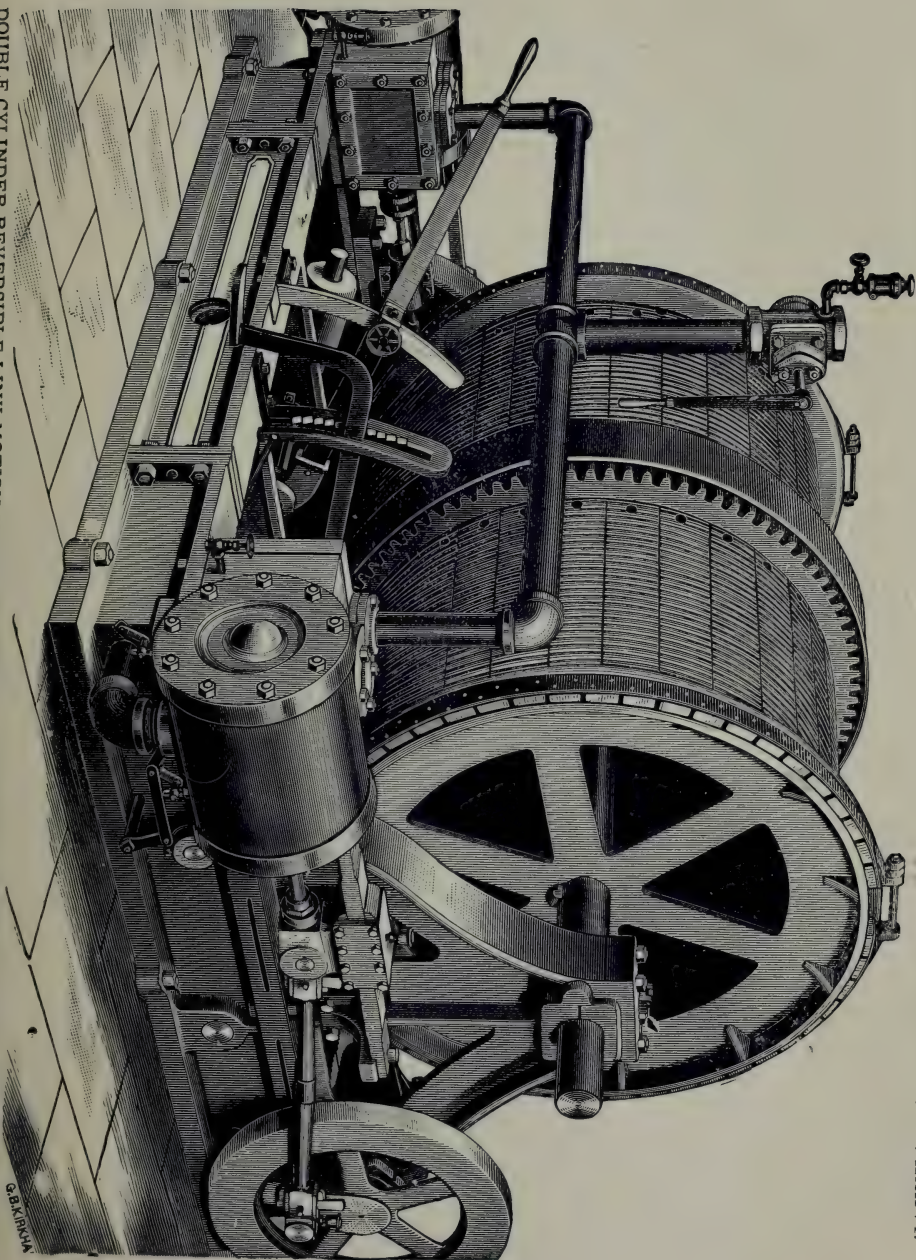
SINKING A LARGE SHAFT WITH INGERSOLL DRILLS. P 176.



EXCAVATING FOR TUNNEL WITH INGERSOLL-SERGEANT ROCK DRILLS. P. 176.



SECTIONAL VIEW OF ECLIPSE DRILL. INGERSOLL-SERGEANT DRILL CO. P. 176.



DOUBLE CYLINDER REVERSIBLE LINK MOTION HOISTING ENGINE. INGERSOLL-SERGEANT ROCK DRILL CO. P. 176.

G.B.K.N.Y.M.

in the highest ridges around Vermilion lake. This made it easy to begin mining the ore, and it was practicable to extract many thousand tons of good ore from open pits or quarries before actual mining operations were resorted to. Such open pits are illustrated in plates xxi, xxii and xxiii. There is but a thin covering of drift material upon the rocks in the iron ore region, and this is easily "stripped" off. The mines or open pits being commenced on the hills obviated the necessity of pumping apparatus to keep out the water, and for the first two or three years no underground mining was done.

Within the last three years, however, regular underground work has been in operation; and at present there is a larger amount of ore extracted from the dark recesses below the open pits than from those exposed to the light of day. In several cases the fourth, fifth and sixth levels have been started, but few of the mines are yet below the third level. The open pit at the Chandler and horizontal entrance to the mine proper are seen in plate xxiii.

The ore in the various pits and shafts of the Minnesota mine at Tower is very hard, and seldom requires timbering to support it. The walls of schist or "soap-rock" are not so firm, and if not supported in some way, slides of rock are apt to occur. In the open pits, which are sometimes more than a hundred feet deep, the walls are kept up by a thin vertical layer of iron ore which is left for that purpose. The mines at Ely are different, since the ore is not so massive, and require some supports.

The ore lenses are vertical or nearly so, and are from ten feet to more than two hundred feet in width, with a varying length and depth, but both greater than the other dimension.

The general method of working the mines is by stopes, pillars of jasper and lean ore being left to support the floors of the levels above. In one or two instances a sort of pillar and stall method is employed, as will be seen from the special description of each mine. The ore is mostly broken to a convenient size for handling, in the mines and is loaded into mine cars from winzes and shoots. These cars are then pushed by hand out to the shaft and hoisted in cages or on skips in the usual way. Plate xxiv shows one of these cars; they are so constructed as to dump automatically when they strike the pocket into which the ore is dropped. Plate xxv gives a view of an uncovered hoist and a car on its way to the pocket or railroad car to dump its load. During the winter no ore can be shipped by lake transportation, and the product of the mines during the winter months is dumped into piles or heaps called stockpiles. Plate xxvi shows the stock-piles at the Chandler mine,

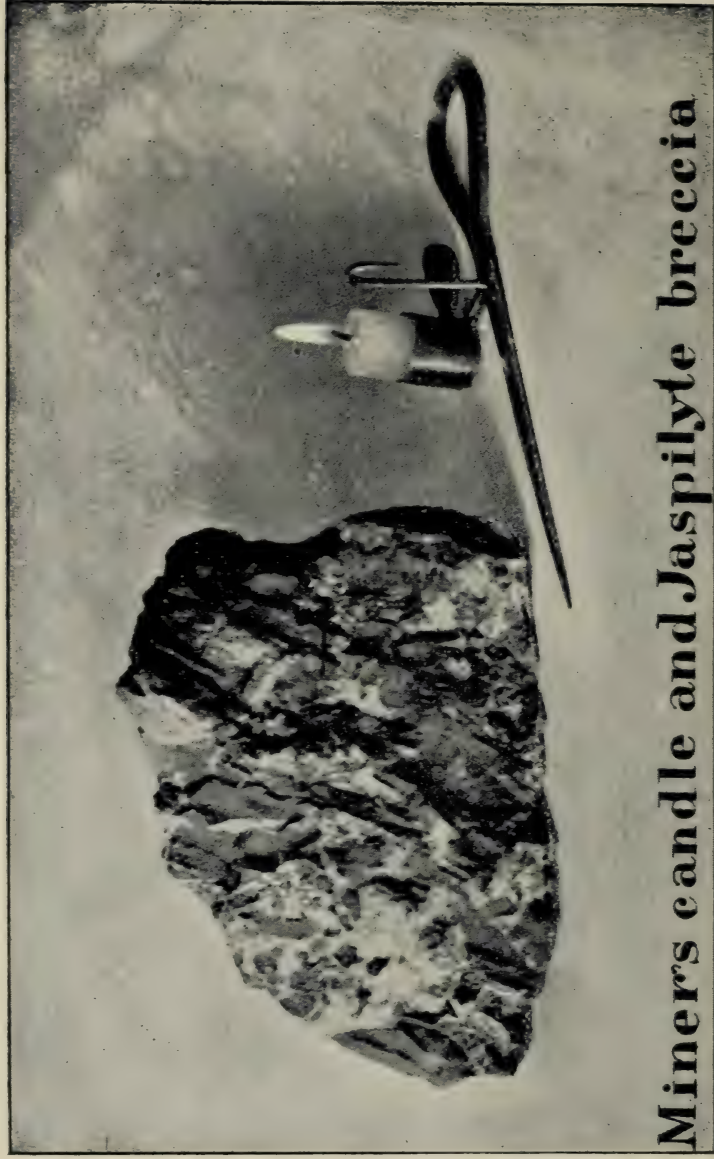
containing many thousand tons of first-class ore. During the summer the ore is dumped into "pockets" from which it is loaded into the cars by means of shutes. Plate XXVII shows one of these pockets, and plate XXVIII is a view of the process of loading the cars from the pockets.

Inasmuch as similar methods prevail in all the mines a general description of the apparatus employed will be given here, and a particular account of each mine will be given afterward.

Drills. The diamond drill has already been described. It is used in Minnesota for the purposes of exploration only; not in any way for the operations of practical mining, though there is no particular reason why it should not be so used in certain positions.

The other two kinds of drills in general use are those run by compressed air, called "power drills", and ordinary hand drills, in both of which the boring is accomplished by percussion. The air which runs the power drills is furnished at a pressure of 60 to 80 pounds per square inch in rubber or iron tubes which are connected with powerful air-compressing engines. The Reynolds Air Compressors are usually employed, and are manufactured by E. P. Allis & Co., of Milwaukee. The illustration on plate XXIX shows one of their double cylinder air compressors. The mining machinery that is being put in at Tower and Ely is of the most improved kind and the appearance of the plants at these places is evidence of the fact that they are there to stay, and that the owners have perfect confidence in the quantity of ore still in store for future mining.

At the Minnesota mine there were 32 Rand compressed air drills (see figure on plate xxx) in use during the season of 1889. They expected to employ double that number in the following season. A uniform pressure of 60 pounds per square inch was used at this mine; but at Ely the drills work under 80 pounds pressure. At Tower two Reynolds compressors capable of running 30 drills each succeeded two Ingersoll compressors of power sufficient to run 16 drills each. Various styles of power drills are shown in the cuts, plates xxx, xxxi, xxxii. The drills weigh from 250 to 300 pounds each, and the tripod on which the drill is mounted weighs 150 pounds more. Two men are required to run a drill, and the bits when dull have to be taken to and from the forge where they are sharpened by other laborers. The cylinder of the air-drill is 3 and $\frac{1}{8}$ inches in diameter. The average length of a stroke is six inches, and there are five or six strokes made while the bit has rotated through a complete circle. The



Miner's candle and Jaspilite breccia

"star bit," fig. 23, is the most common shape. A tool for forging bits is shown in fig. 24. This is commonly called a "Dolly." The holes vary in depth. For the purpose of "shaking" the ore, *i. e.*, cracking it up and enlarging the receptacle for powder without rending it into pieces that can be handled, holes are from 15 to 25 feet deep, and in them Giant powder is charged two or three times. Then it is filled with black powder enough to "throw the ore off,"—sometimes 50 or 60 kegs. There is a regular period for blasting—every three hours, and the sound can be plainly heard for more than forty

FIG. 23.—Star Bit.

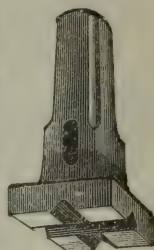


FIG. 24.—Dolly.

miles in the direction of the strike of the rocks. The rate at which holes are bored by these drills varies greatly, owing to the hardness of the ore as well as the temper of the drills, the power of the stroke and the skill and experience of the drillers. Sometimes a drill will bore ten feet in a day, and again it will not accomplish more than ten inches. The holes are two inches or two inches and a quarter in diameter. The continual clatter made by one of these drills at work underground and in hard ore is enough to distract a person, unused to it, and it is almost impossible to speak loud enough to make yourself heard at a distance of six inches from a person's ear. Plates xxxiii and xxxiv illustrate the modern methods of sinking shafts and driving tunnels with power drills.

The hand drills are much after the ordinary pattern. They are pointed or sharpened steel bars which are held upright and turned by one man, and driven down by two others with sledges. They usually make a hole one and a half inches in diameter. At the Chandler mine the holes are seldom over 12 feet long. In underground work the charges are such as to throw the ore out with one shot. In sinking a shaft eight or ten holes are drilled and charged, and all set off at once by a battery. This breaks up the bottom and facilitates handling the rock. Six compressed air-drills did all the work for the Chandler mine in 1889. Plate xxxv is a sectional view of an "Ingersoll Eclipse" drill. Plate xxxva shows the usual miner's candle-stick.

Explosives. An enormous amount of powder and dynamite is used to break up the iron-ore of the Minnesota mine, and considerable, though not so much, at the Chandler mine. The following

table shows the amount of explosive material used in two or three of the pits at Tower, and at the Chandler mine in July, 1889:

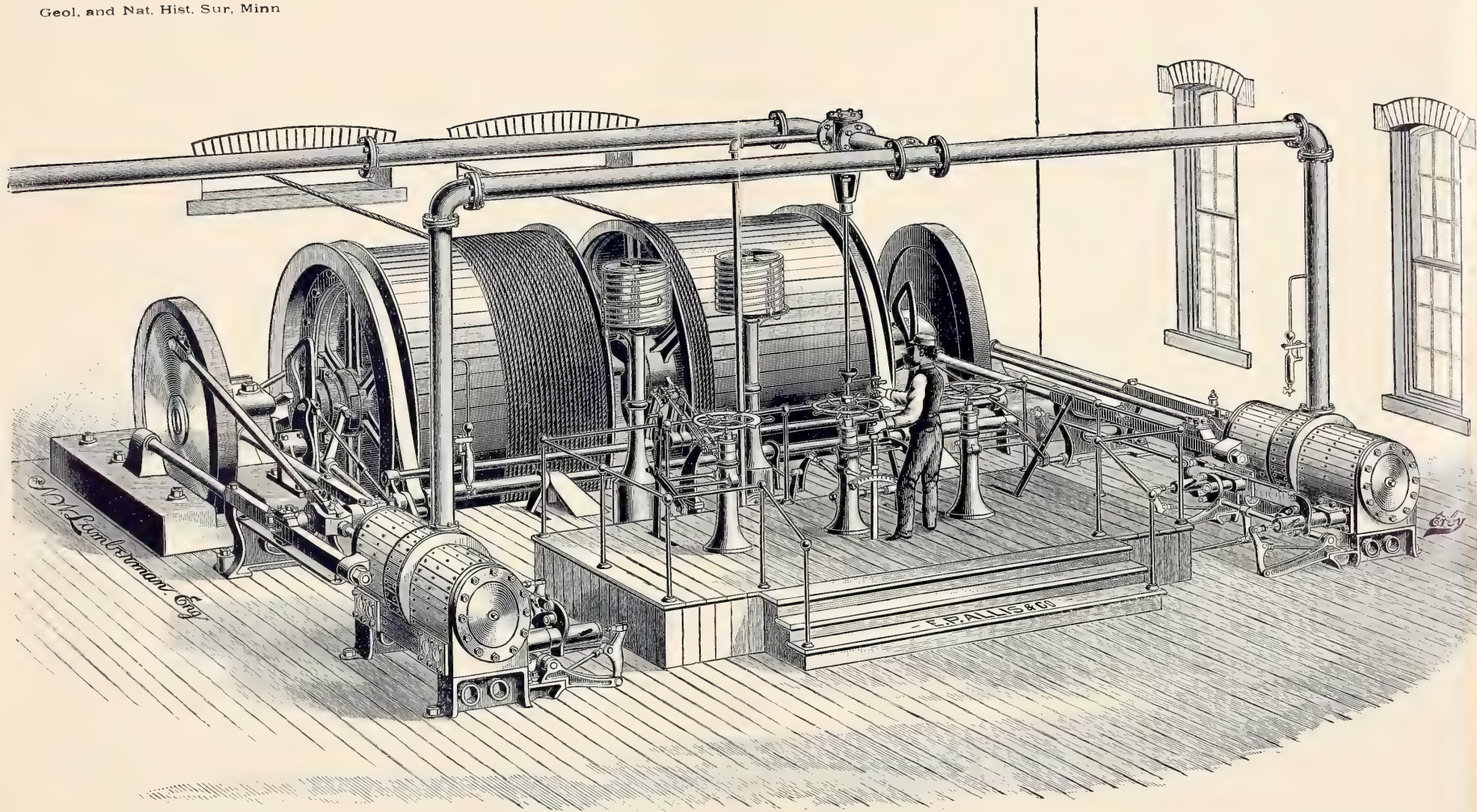
MINE.	50 per cent. giant pow- der.	40 per cent. giant pow- der.	35 per cent. giant pow- der.	Black powder.	Caps.	Feet of fuse.	Battery caps.
Tower pit.....	10,853 lbs.	10,345 lbs.	.....	410 50-lb. kegs.	14,927	61,161	414
Stone and Ely pits	.....	.....	.....	.....	9,295	37,375	.....
Chandler (at Ely)	550 lbs.	3,050 lbs.	2,800 lbs.	50 25-lb. kegs.	2,800	11,450	13 bun's

The cost of this amount of explosive material is no small item, and deducts considerable from the net profit of a mine. The cost, for example, of the explosives, used in the Tower pits of the Minnesota mine in July, 1889, was \$9,246.16. The amount on hand May 1st, 1889, at the Minnesota mine was as follows:

125,346 caps and primers.
 550, 10-foot explosives.
 525, 12-foot explosives.
 213,544 feet single tape fuse.
 73,000 feet double tape fuse.
 2 blasting batteries.
 400 feet leading battery wire.
 12 pounds connecting battery wire.
 149 exploders.

As might be expected, the fragments of hematite fly with great force and velocity for a long distance, and sometimes do injury to property or persons, but seldom fatally injure any one. A few minutes before the time for blasting, for which all the mines have made preparation, a series of warning notes are given by the steam whistles, and all the miners are expected to retire to places of safety. The ground in the vicinity of the open pits where blasting has been carried on, is covered with pieces of good, fresh ore of all sizes up to fragments 50 pounds in weight. Some of them are nearly or quite buried in the earth, having fallen from such a height. The most serious damage done by these flying pieces of ore, is cutting the wire cables which serve for hoisting. These are covered by boards in the most exposed places; but the damage to them is still said to be considerable. It is of course no slight expense to have an 800 foot cable, an inch in diameter, half bisected by a hematite bullet.

Hoisting Apparatus. The hoisting engines are sometimes in the same plant with the compressors, and sometimes in a separate one. The machinery is necessarily very powerful and complex. A brief description of the hoisting plant at the Chandler mine will



HOISTING PLANT. E. P. ALLIS & CO P. 181.

serve to illustrate the mode of hoisting in all the mines. The shafts are usually vertical; but there are numerous long inclines from the open pits. The work of hoisting loaded cars on these is lessened by means of a counterbalancing loaded car of rock or ore, which runs down the opposite side of the slope as the dump car, with which it is connected by a cable, is hoisted up.

At the Chandler mine the hoisting apparatus consists (August, 1889,) of two boilers of 100 horse power each, 6 feet in diameter and 18 feet long, with a three-eighths inch shell. These are tested to stand 180 pounds of steam. They usually carry 90 to 95 pounds, and the safety valve is set at 97.

The two cylinders which furnish the hoisting power direct are 18x48 inches. Each runs at 249 horse power. The hoisting engines run at a rate of 48 revolutions per minute. Large fly-wheels 16 feet in diameter and weighing 8 tons each are used to store up the power and equalize the motion of the engines. They save the power necessary for $7\frac{1}{2}$ revolutions when they are set in motion. The cable is wound up on drums of from four to six feet in diameter. An illustration of a double cylinder reversible hoisting engine with fixed drums and double band brakes is seen in plate xxxvi. This pattern is made by the Ingersoll-Sergeant company. A single drum is used for simple hoisting and lowering of one car or cage; but a double drum is useful where both lowering and hoisting are desired to be performed at once. Electric lights are used in the mines at both Tower and Ely. At the Chandler mine there is a dynamo capable of running 18 two thousand candle power lights. The dynamo is run by steam and has a 10x14 inch cylinder. The dynamo engine runs 300 revolutions a minute and the dynamos over a thousand.

The mines are not very wet, but it is necessary to do some pumping to keep them dry. Of course some shafts are more liable to be wet than others. The crushed condition of the ore in the Chandler and Pioneer mines allows water to percolate through from the surface and makes them wetter than the mines where the ore and rock are both massive. The cost of mining the crushed ore is not so great as that of breaking up and extracting the solid ore; but the expense of pumping and timbering is greater. Knowles and Blake steam pumps are used to keep the water out of the mines as well as to feed the steam engines and diamond drills. These are ordinary mine pumps and do not require a special description.

Timbering. The cost of timbering is comparatively slight. The ore and walls are both quite firm, and require very little artificial support. The shafts are generally timbered with square sets and

left without any casing or sheathing. They are made both single and double, and square or oblong. They are usually sunk in the foot-wall (generally the south wall) about 100 feet from the ore deposit. A cross-cut is then made from the shaft to the ore deposit at the different levels. The distance from the shaft to the ore remains about the same all the way down, since the rocks and ore are so nearly vertical. Timbers of any size are easily and cheaply obtained, as the property in which the mine is located is frequently covered by a pine forest.

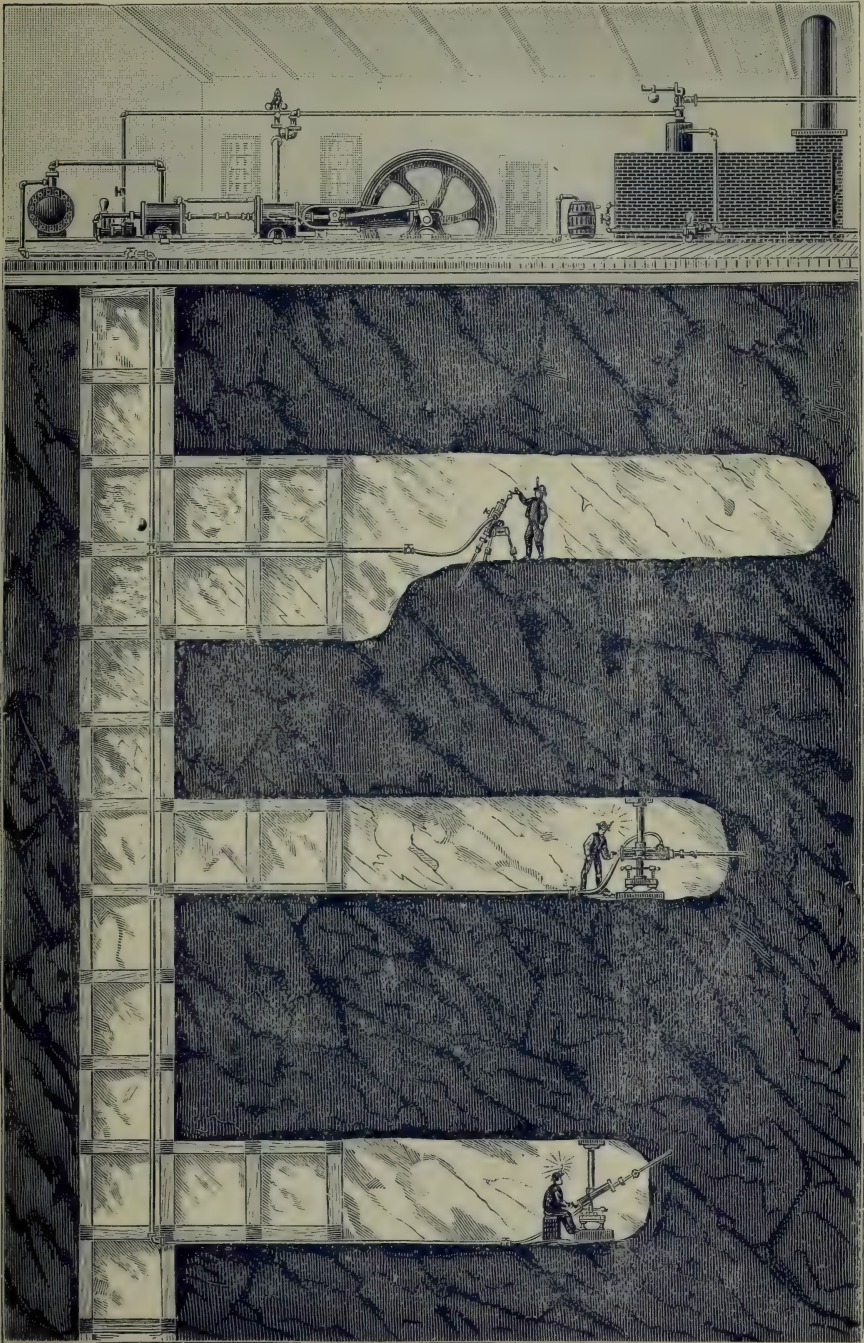
Ventilation. There is usually no lack of good air in the mines, though occasionally a drift or gallery is found where the smoke from the miners' candles, the gases produced by blasting and the exhalation of the laborers have combined to produce a very bad atmosphere. The air which is forced into the mines under pressure to work the power drills, is a great aid to ventilation. Where two or three power drills are constantly at work in a level, open at only one end to a shaft or open pit, the air is kept moderately fresh. The trickling waters, too, absorb a part of the carbonic acid and other gases, and help to purify the air.

Natural means are resorted to, to produce a current of air through some of the mines, as, for instance, the Chandler. The two shafts are connected under ground at the lowest level, allowing air to pass freely from one shaft to the other. The hoisting frame of the highest shaft is then covered over with boards and closed up so that air can escape only from the top, as from a chimney 50 or 75 feet high. The other shaft is left open at the level of the ground. A regular circulation of air is thus obtained by the draught up the chimney, which draws air down the open shaft and up through the mine. On warm, sunny days the heat of the sun on the air enclosed within the boarded-up shaft house starts up and maintains a noticeable current of air. The lowering and raising of cages is another agent which assists somewhat in changing the air in the vicinity of the shaft.

When the mines become deeper the question of ventilation will become more prominent, and will demand some attention from the mine operators. At present the ventilation almost takes care of itself.

Equipment. The frequent outcropping of the iron ore lenses almost or quite on the surface of the ground, makes it a simple matter to begin the extraction of iron ore on a small scale, and a man without any capital can begin to mine iron ore, if he has it on his property, without enlisting the aid of capitalists.

For the operation of a large mine, however, an equipment costing a large sum of money is necessary at the outset; and money



IDEAL ILLUSTRATION OF A MINE, SHOWING SHAFT, TIMBERING, LEVELS, HOISTING ENGINES AND AIR COMPRESSOR, WITH METHOD OF USING POWER DRILLS. RAND DRILL CO.

must be at hand to keep this plant in running order, as well as to pay the employés. To give an idea of the various kinds of material required to operate a mine like the Minnesota mine at Tower, a list of the machinery in use in that mine during the summer of 1889 is inserted here. This equipment was to be nearly doubled in a year from that time.

Cars, Skips and Derricks.

At Pit No. 1,—

4 end dump, 2 ton iron cars.
3 side dump, 2 ton iron cars.
1 end dump, 1 ton wood car.
1 one ton bucket.
1 cage.

At Pit No. 3,—

12 end dump, 2 ton iron cars.
3 end dump, 1 ton wood car.
1 two ton skip.

At Pit No. 5,—

6 end dump, 2 ton iron cars.
1 end dump, 2 ton iron car.
1 one ton skip.
1 cage.

At Montana shaft,—

1 one ton bucket.
1 end dump, 1 ton wood car.

At Montana pit,—

6 end dump, 2 ton iron cars.
2 side dump, 2 ton iron cars.

At No. 6 Pit,—

8 end dump, 2 ton iron cars.
1 side dump, 2 ton wood car.
1 cage.

At Alaska shaft,—

1 end dump, 1 ton wood car.
1 one ton skip.
1 cage.

At No. 8 pit,—

17 end dump, 2 ton iron cars.
1 end dump, 1 ton wood car.
1 one ton skip.
1 cage.

At No. 9 scam,—

3 end dump, 2 ton iron cars.
1 end dump, 2 ton wood car.

At No. 9 pit,—

2 one ton wood cars.
2 one ton buckets.

At No. 17 scam,—

1 end dump, 2 ton iron car.
1 end dump, 1 ton wood car.

At No. 19 scam,—

1 end dump, 2 ton wood car.

At No. 1 stock-pile,—

2 wooden box stock-pile cars.

At No. 2 stock pile,—

1 wooden box stock-pile car.

At No. 3 stock-pile,—

2 iron stock-pile cars,
1 end dump, 2 ton iron car,
5 wooden stock-pile cars.

At No. 5 stock-pile,—

5 iron stock-pile cars.

At No. 7 and No. 8 stock-pile,—

8 iron stock-pile cars.
1 wooden stock-pile car.

At No. 9 stock-pile,—

6 wooden stock-pile cars,
1 iron stock-pile car.

At No. 16 stock pile,—

2 wooden stock-pile cars.

At No. 17 stock-pile,—

2 wooden stock-pile cars.

At No. 19 stock-pile,—

3 wooden stock-pile cars.

At No. 10 pit,—

4 end dump, 2 ton iron cars,
1 side dump, 2 ton iron cars.
2 1-ton iron buckets,
1 cage.

At No. 11 pit,—

1 turntable iron car.

At No. 10 stock-pile,—

4 wooden stock-pile cars.

At Yard,—

5 1 ton iron buckets.
1 1 ton skip.

At general blacksmith shop,—

2 2 ton iron cars.
1 cage.
4 derricks.
4 hoists.

Machinery.

No. 1 Engine,—

- 1 portable boiler on skids.
- 1 20-ft. hoisting drum with 6x8 engine.

No. 3 Engine,—

- 4 6 ft. hoisting drums with ten 18x24 engines.
- 2 3½ ft. hoisting drums with two 10x12 engines.
- 2 5x16 boilers.
- 1 No. 5 Knowles feed pump.

No. 4 Engine,—

- 1 No. 3 Knowles pump.
- 1 3½x 11 Allis feed water heater.
- 2 4 ft. drums with 14x20 engines.
- 1 20 foot portable hoist.
- 3 air receivers.
- 2 20x30 Ingersoll air-compressors.
- 3 5x16 boilers, with No. 5 feed pump.

No. 6 Engine House,—

- 2 5 ft. hoisting drums, with engines.
- 1 20 ft. portable hoist, with engine.
- 2 3½ ft. hoisting drums, with engine.
- 2 5 ft. hoisting drums, with engine.
- 2 5x16 boilers, with No. 6 Knowles pump.
- 1 feed water-heater.

No. 7 Engine,—

- 1 No. 7 Ames locomotive boiler.
- 1 5 ft. drum with engine.

No. 8 Engine,—

- 1 new Economizer locomotive boiler.
- 1 No. 1½ Blake feed pump.
- 2 20 ft. portable hoists.

Armstrong Engine House,—

- 1 upright boiler.

At lumber yard,—

- 1 3x6 upright boiler.
- 1 5x16 boiler.
- 2 4x16 boilers.

Engine Houses.

8 engine houses, various dimensions.

Other Buildings.

Warehouses, change houses, heating houses, barns, blacksmith shops, ice-house, laboratory, post office, general offices, hospital, pest-house, shoeing shops, shipping offices, electric light plant, repair shops, drill shops, lumber office, powder houses, time offices, dwelling houses, etc.

Diamond Drills.

- 1 Economizer loco boiler, 10 horse power.
- 1 No. 4 Ames loco boiler, 12 horse power.
- 1 No. 3 Ames loco boiler. 8 horse power.
- 1 B Sullivan diamond drill, 2,000 feet.
- 2 Bullock champion drills, 800 feet.
- 1 Bullock "Beauty" drill, 500 feet.

- 100 Karats carbons.
- 2 No. 1½ Blake pumps.
- 2 Worthington pumps.

Oils.

- 6 oil tanks.
- 4,516 gallons kerosene.
- 320 gallons miner's oil.
- 1,111 gallons block oil.
- 675 gallons Eagle machine oil.
- 107 gallons vacuum cylinder oil.
- 150 gallons common cylinder oil.
- 93 gallons spring oil.
- 200 gallons lard.
- 300 lbs. axle grease.
- 600 lbs. patent grease.
- 150 gallons Eldorado oil.

Fuel.

- 840 tons steam coal.
- 16 tons egg coal.
- 124 cords soft wood.

At Two Harbors,—

- 3,145 tons steam coal.
- 250 tons Blossburg coal.

Steam Pumps.

- Swamp pump.
- 1 upright tubular boiler, 7 ft. 9 in.
- 1 No. 6 Knowles plunger pump.
- 1 tank, 60,000 gallons.
- 1 No. 6 Knowles pump.
- 1 B mining pump.
- 6 No. 6 Knowles pumps.
- 2 No. 4 Knowles pumps.
- 1 No. 6 Blake pump.
- 1 duplex Knowles pump.
- 1 No. 6 Dayton pump.
- 7 tanks, various sizes.

Machine Shops.

- 1 Locomotive boiler, with No. 4 Knowles pump.
- 1 engine, 11x16.
- 1 38 inch lathe, with 2 running blocks.
- 2 18 inch lathes.
- 1 Peerless pipe-cutter.
- 1 Walcott shaper.
- 1 bolt-cutter.
- 1 drill-press.

Wire Rope.

- 5,367 feet 1½ inch wire rope.
- 8,979 feet ¾ inch wire rope.
- 2,568 feet ¾ inch wire rope.
- 2,047 feet 7-8 inch wire rope.
- 3,978 feet 1 inch wire rope.

Miscellaneous.

17 shafts.
 10 shaft houses.
 8 coal docks and pockets.
 Explosives, see page 180.
 Assay laboratory at Tower.
 Assay laboratory at Two Harbors.

The cost of these various adjuncts to a mining plant may be stated approximately as follows:

Cars, skips and derricks.....	\$16,000.00
Machinery.....	66,000.00
Engine houses.....	5,000.00
Dwellings.....	64,000.00
Other buildings.....	32,000.00
Air pipes.....	5,238.00
Electric lights.....	5,000.00
Supplies.....	72,000.00
Oils.....	3,000.00
Fuel.....	32,000.00
Machine shop.....	8,000.00
Blacksmith shop.....	12,000.00
Laboratories....	4,000.00
Pumps &c.....	8,000.00
Wire rope.....	4,000.00
Shafts &c.....	36,000.00

Total cost of plant \$372,238.00

The cost of explosives at Tower is several thousand dollars per month, and the other materials which are used up cannot be estimated exactly. The number of miners employed in these mines is sufficient to form a small city. During the summer of 1889 there were more than 1,600 men employed at the Minnesota mine, and 650 at the Chandler. In 1890 the Minnesota Iron company intended to enlarge their force to 2,000 men. At the Chandler mine the ore extracted is about a ton and a half a day per man. At the Minnesota mine it is less, and is about one and one-tenth tons per man. This is due to the greater amount of drilling and breaking necessary in the hard ore of the Minnesota mine. The pay-roll at the Minnesota mine is over \$70,000.00 a month.

Methods of sampling and analyzing, and quality of the ore. Inasmuch as the Minnesota Iron company's land is considerable, and ore is taken from pits which vary in their content of metallic iron and of phosphorus, it is necessary to keep a close watch on all the

ore that is mined in order to have it properly graded. The ore is hand-picked into three grades, by men who can tell at sight when a piece of ore has too much quartz in it to belong to a certain grade. It is pretty well known what kind of ore is being obtained from each pit. One pit or mine may vary considerably in the per cent of metallic iron, but not usually in the per cent of phosphorus.

The ore is sold by contract according to grade. There were six grades of ore sold in the season of 1889, as follows:

Vermilion, 66.66 per cent. to 67 per cent. Fe., High Phosphorus.

Soudan, 65.00 per cent. Fe., High Phosphorus.

Red Lake, 62.00 per cent. Fe., High Phosphorus.

Minnesota, 66.66 per cent. Fe., to 68 per cent. Fe. Low Phosphorus.

Braddock, 65.00 per cent. Fe., Low Phosphorus.

Nipigon, 62.00 per cent. Fe., Low Phosphorus.

"High Phosphorus" means that the ore contains over six hundredths of one-per cent. of phosphorus, and is above the Bessemer limit. "Low Phosphorus" means that the ore contains less than six hundredths of one per cent. of phosphorus, and is adapted for making Bessemer steel.* No regularity has been discovered in the general trend of phosphorus streaks. Outside samples, (*i. e.* samples from the outer edges of ore-lenses,) and inside samples were analyzed, but did not show any constant difference. In one lens there would be more phosphorus in the outside ore than in the ore from the interior of the mass; in another lens the reverse would be found to be true.†

The general character of the ore from a pit is quite constant, and at the Minnesota mine the nature of the ore in the various pits is as follows:

Pit No. 1 is high phosphorus. (Stuntz mine).

Pit No. 2 is low phosphorus. (Old Stone mine).

Pit No. 3 is low phosphorus. (Old Stone mine).

Pit No. 4 is low phosphorus. (Old Stone mine).

Pit No. 5 is low phosphorus. (New shaft).

*The rule usually adopted for determining whether any iron ore is to be ranked as Bessemer is as follows: The figures standing in the places of hundredths and thousandths, in the decimal expressing the percentage of phosphorus, must be taken together as an integer, no higher than the integer that expresses the percentage of metallic iron in the ore. Thus, the following would be Bessemer ores: Fe. 68.44, P. 0.067; Fe. 44.10, P. 0.033; Fe. 68.43, P. 0.011; the following would not be Bessemer ores: Fe. 68.44, P. 0.069; Fe. 39.45, P. 0.041.

** "In a series of twenty-three samples taken from lumps of ore along seams, the phosphorus was determined in the interiors of the lumps and in the scale along the faces. In every sample of non-Bessemer ore the phosphorus was higher in the lump than in the scale, and in Bessemer samples the scale was considerably higher than the lump, with the exception of three cases in which the scale was lower by .002 per cent., .003 per cent. and .006 per cent. respectively, (100 per cent. = whole sample, not phosphorus.)" C. T. Waters, (In a letter dated June 27, 1890.)

Pit No. 6 is low phosphorus. (Old Ely pit).
 Pit No. 7 is high phosphorus. (Tower mine).
 Pit No. 8 is high phosphorus. (Tower mine).
 Pit No. 9 is low phosphorus. (West Tower mine).
 Pit No. 10 is high phosphorus. (Lee mine).
 Pit No. 11 is low phosphorus. (East Lee).
 Pit No. 12 is low phosphorus. (Too much sulphur). (Breitung).
 Pit No. 13 is high phosphorus. (West Breitung).
 Montana is low phosphorus.
 Alaska is high phosphorus.

The amount of each grade of ore mined and shipped between December 1, 1888, and August 1, 1889, from the Minnesota mine, is as follows. All but 12,797 tons of this was shipped between April 22, 1889 and August 1, 1889:

	Vermilion.	Soudan.	Red Lake.	Minnesota.	Braddock.	Nipigon.	Total.
July shipments.....	1,501	11,165	14,713	50,781	3,377	8,228	103,669
Previously reported.....	4,407	21,207	22,285	90,302	10,082	22,906	210,853
Total.....	59,476	32,372	36,998	141,083	13,459	31,134	314,522

From this table it may be seen that considerably more than half the ore mined is low in phosphorus, and that *nearly half of it contains over 65 per cent of metallic iron and less than six hundredths of one per cent of phosphorus.* Such a showing can probably be made by no other mining region in the world.

The theoretical per cent of metallic iron in pure hematite being but 70, it leaves less than 5 per cent to be accounted for as impurities. This is mainly silica, in the form of quartz. Sulphur is rarely found in quantities sufficient to be determined. The amount of phosphorus is the all-important thing, and in order to be sure of this the ore is analyzed three times, once at the mine, once at Two Harbors and once at the blast furnace, before it is smelted; and the steel goes through further processes of chemical analysis.

Sampling and assaying. A chemist and one or two "samplers" are continually employed to make these determinations. The miners put the ore in stock-piles, in pockets or in cars. The sampler then goes to these stock-piles or cars with a hammer and bag. With a tape-line or a string he goes diagonally or lengthwise across a car load, taking a small piece of whatever the knot, which he has made in his string every 12 inches, falls on. It may be jasper or

rock or ore. The samples from one or more cars, sometimes as many as six, are ground up and pulverized, first under a steam crusher, and then by hand, care being taken to keep samples from different mines separate. After this ore has been dried in a steam bath the chemist takes a certain portion of it, about 5 grains, and determines the per cent of iron and of phosphorus. Duplicate samples are generally worked so as to make no mistake. The silica is not usually determined by actual tests, but can be ascertained by the method of differences. The methods of volumetric analysis given in Blair's *Chemical Analysis of Iron* are usually employed with occasional slight variations.

When a new pit is opened or a new level commenced complete analyses are made of the ore. These seldom show any great variation.

The reports from these analyses are carefully made and as carefully examined by the general manager or superintendent of the mine. The amount and kind of ore mined from each pit and shipped from each pocket is recorded in the record books of the laboratory and on tabulated slips as follows. The analyses below are given simply as samples of the chemists' reports:

POCKET NO. 5, BRADDOCK GRADE.

Date.	No.	Metallic iron,	Phosphorus.	Remarks.
June 5, 1889.....	2334	64.90	.053	2 cars.
June 11, 1889.....	2354	65.00	.055	2 cars.
June 22, 1889.....	2389	65.30	.056	4 cars.
June 28, 1889.....	2415	65.95	.047	3 cars.

POCKET NO. 5, MINNESOTA GRADE.

Date.	No.	Metallic iron.	Phosphorus.	Remarks.
June 5, 1889.....	2333	67.95	.045	3 cars.
June 10, 1889.....	2349	67.60	.051	3 cars.
June 22, 1889.....	2388	67.80	.048	6 cars.
June 25, 1889.....	2397	66.20	.049	2 cars.
June 28, 1889.....	2414	67.90	.047	5 cars.

POCKET NO. 9, NIPIGON GRADE.

Date.	No.	Metallic iron.	Phos-phorus.	Remarks.
June 1, 1889.....	3326	65.30	.038	3 cars.
June 5, 1889.....	2336	64.40	.036	1 car.
June 5, 1889.....	2337	60.85	.059	2 cars from No. 2 stockpile.

POCKET NO. 9, MINNESOTA GRADE.

Date.	No.	Metallic iron.	Phos-phorus.	Remarks.
June 5, 1889.....	2335	67.70	.044	2 cars.
June 11, 1889.....	2350	65.50	.041	4 cars.
June 15, 1889.....	2366	67.60	.037	4 cars from No. 1 stockpile.
June 25, 1889.....	2400	68.55	.037	4 cars.

At the end of each month averages are made which show what amount of ore has been furnished by each mine or pocket during that space of time and what the quality of it was. Below is given the average for July, 1889:

Minnesota Grade.

Mine.	Fe.	P	Cars Shipped.
No. 5 Pocket.....	67.511 per cent.	.0544 per cent.	32
No. 9 Pocket.....	67.783 per cent.	.0393 per cent.	24
No. 2 Pocket.....	65.517 per cent.	.0455 per cent.	25

Braddock Grade.

No. 5 Pocket.....	63.325 per cent.	.053 per cent.	6
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Nipigon Grade.

No. 2 Pocket.....	59.20 per cent.	.052 per cent.	2
No. 3 Pocket.....	64.50 per cent.	.121 per cent.	5
No. 5 Pocket.....	62.175 per cent.	.0605 per cent.	7

Vermilion Grade.

No. 1 Pocket.....	67.45 per cent.	.085 per cent.	5
No. 7 Pocket.....	67.15 per cent.	.173 per cent.	2
No. 8 Pocket.....	67.57 per cent.	.1219 per cent.	23
No. 19 Pocket.....	66.166 per cent.	.1344 per cent.	12

Soudan Grade.

No. 1 Pocket.....	66.213 per cent.	.0553 per cent.	16
No. 7 Pocket.....	67.108 per cent.	.1578 per cent.	17
No. 8 Pocket.....	65.088 per cent.	.0993 per cent.	15
No. 13 Pocket.....	60.50 per cent.	.145 per cent.	..

Red Lake Grade.

No. 1 Pocket.....	62.55 per cent.	.0793 per cent.	7
No. 7 Pocket.....	66.80 per cent.	.167 per cent.	4
No. 9 Pocket.....	61.15 per cent.	.053 per cent.	7
No. 10 Pocket.....	63.00 per cent.	.114 per cent.	..
No. 13 Pocket.....	62.15 per cent.	.104 per cent.	21

If a certain grade of ore has been a little too high in phosphorus for one month, better ore than the guarantee calls for is shipped in that grade the next month, and the required average is maintained.

Distribution of phosphorus in the ore. Mr. David H. Browne, after a careful examination of the ore of the Ludington mine, Iron Mountain, Michigan, with reference to its content of phosphorus in different parts of the ore bodies, reached the conclusion that ore high in phosphorus was most prevalent near the hanging wall, decreasing toward the foot-wall, and that in lenses that pitched west the ore at the eastern end contained more phosphorus than that at the western end, and that, in general, ore from the levels near the surface contained more phosphorus than that from greater depths. The ore here is a soft, friable, bluish-black hematite, occurring in thin laminæ which cleave very readily from each other in the direction of the strike. These layers alternate, in places, with thin seams of calcium-magnesium carbonate. He says:

"The fact that phosphorus exists as calcium phosphate led me to infer that some proportion between the percentage of lime and phosphorus might be found to exist, but such inference was not verified in practice. An ore containing 2 per cent. of lime may contain almost no phosphorus, or may run high above Bessemer limit, nor was any proportion manifest between the percentages of iron or silica and phosphorus. I have noticed jasper vary as much in percentage of phosphorus as any iron ore, and similarly a lean ore is just as likely to be Bessemer as non-Bessemer. The only difference I could find between Bessemer and non-Bessemer was this: As a rule a soft blue hematite high in phosphorus has a brighter and more specular appearance than non-Bessemer ore of the same value in iron. This distinction, slight as it is, will not always hold good, and the separation of such ores must be guided solely by chemical analysis." *

It will not be warrantable to apply these statements unqualifiedly to any mine except that which Mr. Browne examined. We are led to suspect that the Ludington ore, and the formation in which it occurs, may not be paralleled by the Vermilion range ores of Minnesota, but rather by those hematites found in the Mesabi range.

Still, in order to make some comparisons with the exploited ores of Minnesota, Mr. C. T. Waters has conducted some chemical re-

* Am. Jour. Sci. (311) xxxvii. 300.

searches having in view some of the same problems, and he has kindly furnished the following statement giving some of his results:

SOUDAN, MINN., OCT. 30, 1890.

Prof. N. H. Winchell, Minneapolis:

DEAR SIR.—In speaking with you, we referred to Mr. Browne's paper on the occurrence of phosphorus in the Ludington mine. He speaks of the "*bright blue hematite*" as being high in phosphorus, but says he can not grade the ore as Bessemer and non-Bessemer without chemical analyses.

At the time his paper was published, I had been for some time looking for a method by which we could separate our ores, with some degree of certainty, without recourse to analysis.

I found that while in most cases I could determine with reasonable accuracy the per cent. of phosphorus by the shade of color of the powdered sample, the method was not sufficiently reliable to warrant its use.

I find that the proportions of iron, silica, etc., in quantities of our ore seems, as Mr. Brown states also for the Ludington ore, to have no connection with the amount of phosphorus, although in 34 instances of determination made in the gangue on the face of seams and in the clean ore behind the face—with three or four exceptions, in which the phosphorus in gangue and clean ore were nearly the same, (about .060 per cent.)—I found the gangue of Bessemer ore to contain more, and of non-Bessemer ore to contain less phosphorus, than the clean ore.

By *Bessemer*, I mean what we ship as Bessemer, that is, .055 per cent. and below, of phosphorus. My conclusion as to *blue* ore is the opposite of Mr. Browne's. I used for examination the powder prepared for analysis. The *red* ore which is *brighter*, runs higher in phosphorus than the *blue* ore, which is *duller* but seemingly of a finer texture. The *blue* powder packs closer and gives a smoother surface when rubbed down with a spatula.

These observations apply more to our first class ores (68.00 to 68.50 Fe. about,) than to our second and third classes (65.00 and 62.00 Fe.), which in Bessemer ore are more brown than blue.

There is a marked difference in the color of the powdered ore from the different workings; that from non-Bessemer pits being very red, and that from Bessemer pits being quite blue.

After becoming accustomed to the peculiar shades of color, it is possible to say, nearly always, from what pit a given sample is, and whether it is higher or lower in phosphorus than any other sample from the same working.

I should say that the amount of phosphorus does not influence the shade and color of these ores, but that the variations of shade and color are due to the same causes as is the variation in phosphorus. All this applies, of course, only to our ores here.

I have tried, qualitatively, five samples of so-called "soap rock" for manganese. They were from the following: 1. Tunnel at East Breitung. 2. No. 7 shaft, 25 feet from the ore body. 3. Railroad cut near the Stone pocket. 4. Butte shaft, 60 feet from ore body. 5. Montana shaft, 75 feet from ore body. Of these, numbers 1 and 4 were the only ones which gave me indications of any manganese. These two I started to work quantitatively, but did not complete, as there was in five grains so small a precipitate of the oxide that it would be almost indeterminable.

Yours very truly,

C. T. WATERS.

DESCRIPTIONS OF THE SEPARATE MINES.

The Minnesota Iron Company. The condition of the excavations is constantly changing. Some idea of the various openings that had been made at that date was conveyed to the public in the annual report for 1886, with illustrations of the shapes at the surface, and to the first, and sometimes the second level. Great changes have taken place since then. The pits are all deeper, and in some have been continued downward to the fifth and sixth levels. They have been extended east and west, both as open pits and especially in under ground working. At the same time some of the original excavations, having been abandoned as open pits, are slowly being filled again by dumping of the rock and refuse from the other pits.

From Mr. H. A. Wilcox the depths of the principal pits were obtained (Oct. 1890), and from captain Williams general estimates of the underground excavations on the various levels.

Shaft No. 1, (Stuntz), is 238 feet deep; has three levels, one at about 100 feet, one at 170 feet and the third at the bottom. On the first floor work has been extended about 300 feet in each direction (east and west) from the shaft; and on the second about 150 feet each way. On the third floor work has been prosecuted about 50 feet each way from the shaft. These drifts, which have the width (north and south) of the ore body, average from 13 to 15 feet wide.

Shaft No. 2 (east end of the old Stone mine), has been abandoned, but was perhaps 75 feet deep.

Shaft No. 3 (Stone) is 367 feet deep, and has six floors. The first is at a depth of 117 feet, the second at 147 feet, the third at

197 feet, the fourth 217 feet, the fifth 267 feet, the sixth at the bottom, 367 feet below the surface. On the first level the working has gone from 500 to 600 feet between the extreme ends, with a width of about 20 feet, average. On the second level the work has gone about 150 feet east, but not any west; width about 20 feet. On the third level the working has been extended 250 feet west and 75 feet east. On the fourth floor it has gone 100 feet to the east, but on the west the ground is left for future working. On the fifth floor the work is 200 feet toward the west, and about 100 feet toward the east. On the sixth level it is extended 35 feet, and here the ore ceased in that direction. On the west the work is at about 150 feet from the shaft. Between the fifth and sixth floors the ore body pinched out, at least ceased; and the ore was found, and is now being worked, on the sixth level, about 30 feet further to the south, and is about as wide as before. The upper portion of this new ore was shaped like a hog's back, and at first was accidentally encountered in sinking the shaft in the rock of the south wall. It is apparently a new lens.

Shaft No. 4 was an open pit at the Stone, now tributary under ground with No. 3; not recognized.

Shaft No. 5 (East Ely, or east end of the Ely) is 364 feet deep. This is connected with No. 3 at the third level. The floors are at about the same places as those of No. 3. On the first floor it is excavated about 100 feet each way; on the second floor 75 feet toward the west and 175 feet toward the east. On the third floor it is connected on the east with No. 3, and on the west, at 200 feet, is connected with No. 6. On the fourth floor nothing has been done toward the east, but toward the west about 150 feet have been taken out. On the fifth floor the excavation has been carried about 75 feet toward the east, but not at all toward the west. At the bottom working has been carried about 25 feet east, and about 15 feet west.

Shaft No. 6 (Ely) is 230 feet deep, and is an open pit down to 130 feet. It has two floors. On the first floor the extreme ends are 150 feet apart. On the second floor the working has extended about 100 feet on the west, and on the east there is a connection with No. 5.

Shaft No. 7 (new East Tower) is 259 feet deep, and has four floors. The first floor is down about 113 feet, the second 153 feet, the third 203 feet, the fourth 259 feet. On the first floor the working has extended about 250 feet, from east to west, extreme length; on the second, in like manner, about 150 feet, and on the third

about 100 feet. At the fourth level the ore is not yet reached in the cross-cut from the shaft.

Shaft No. 8 (old East Tower) is about 310 feet deep. This pit was worked, open, down to about 150 feet. The next floor (first floor) is about 50 feet below, and work has extended about 300 feet between the extreme ends. The second level is about 50 feet lower, and the excavated interval between the extreme ends (east and west,) is about 175 feet. The third level, which is 65 feet lower, is not yet worked. The cross-cut from the shaft is simply in the ore.

Shaft No. 9 (West Tower) is 350 feet deep. This was worked as an open pit to the depth of about 300 feet. At the depth of 200 feet a drift was worked westward, underground, 150 feet. The next floor is at the bottom. A drift has been run here toward the west, in the footwall (*i. e.* the southern wall), about 14 feet, not any east; not yet in the ore.

Shaft No. 10 (North Læe, sometimes called West Lee,) has a depth of 135 feet, and is worked as an open pit, with an extent east and west of about 200 feet.

Shaft No. 11 (old South Læe, sometimes described as East Lee) is abandoned. There was no real shaft. Ore and rock were hoisted with a derrick from an extreme depth of perhaps 75 feet.

Shaft No. 12 (Breitung, situated toward the west, across the spur-track, southwest from the irregular main old Breitung), has an estimated depth of 150 feet. The first floor is down 117 feet, and runs west about 25 feet, none east. The second floor is not yet reached by the shaft now being sunk.

Shaft No. 13 (part of the old Breitung, south of the west end of the West Tower), is 147 feet deep. Open pit 87 feet. There is one floor below, worked about 150 feet between the ends.

Alaska shaft has two floors, and is 287 feet deep. One floor is at 180 feet from the surface, and is extended about 150 feet west, none east. The bottom floor, 47 feet lower, is extended about 180 feet or 190 feet east and west. The shaft is down about 60 feet below that.

Montana shaft is 249 feet deep, and has two floors; one is at the bottom of the open pit (*viz.* at 109 feet) and the other is at 75 feet lower, on which work has been extended 300 feet east and west. Seventy feet still lower working has extended about 20 feet between extreme ends.

Butte shaft is 150 feet deep and has two floors. At the depth of 100 feet a cross-cut was put in from the shaft to the ore, but no mining has been done there. At 50 feet still lower they put in a cross-cut and struck the ore again. No mining has been done.

Armstrong shaft, which is 150 feet deep, has been worked only so far as to drift in at the bottom and strike the ore.

All the east-and-west workings would have an estimated average width of about 25 or 30 feet. In No. 8 shaft, however, the working is in some places 50 or 60 feet wide. There are numbered workings running to about 20, representing small pits and scrams, sometimes worked by contract by "scrammers."

The Chandler mine. This mine is now operated by the Minnesota Exploration Company. When parties of the survey first visited the location of the Chandler mine* (or Patterson's trenches) in July 1886, they found several north-and-south trenches from two to six feet in depth, running, as supposed, across the ore bed. The bottoms of the trenches were in a red, soft earth which was supposed to be hematite ore *in situ*. A close inspection was made along the bottoms and in the earth thrown out, and the owners were told the material was not *in situ*, but had been moved and mingled with a little drift material, and was indicative of a deposit of soft ore in the near vicinity. It proved subsequently that the main deposit from which the red earth was largely derived, was situated about seventy-five feet further toward the north, and on it the first ore was taken out in an open pit. The railroad did not reach the Chandler property till late in the season of 1888 and the amount of ore shipped that year (54,612 tons) shows that the ore was easily mined and that the management of the mine did a good season's work in a very short time.

During the following year the major portion of the output came from this open cut, although underground mining was commenced and considerable ore was raised through the two shafts now known as Nos. 1 and 2. The season of 1889 closed giving the Chandler mine the credit for the production of 316,120 tons of a high grade Bessemer hematite. This for the second season's work is the best record gained by any mine in the lake Superior district. All of the ore shipped from the Chandler mine has been raised through two vertical, two-cage shafts. Shaft No. 2 is located about 370 feet west of the boundary line between this property and the Pioneer, and 190 feet south of the north line. This shaft is 300 feet deep. Shaft No. 1 is 720 feet west of No. 2 and about 200 feet south and is 250 feet deep. The formation is generally nearly vertical and the ore body has a pitch to the east of about thirty degrees. This with one or two exceptions is the situation of all the ore bodies in this region and while the walls of the deposits have positions vary-

*See the fifteenth Annual Report p. 325-26.

ing from the perpendicular to nearly horizontal, the pitch remains about the same.

The mode of mining employed here is what is known as the caving system. The levels are all made sixty feet apart, and in the ground lying above the floor drifts, cross-cuts and raises are driven in such directions as to leave blocks of ore which are afterwards milled down into the tram cars, pushed to the cage and raised to the surface. This ore is at first taken from the blocks at the extremities of the body opened up and worked out towards the shafts, the surface being allowed to fill the cavity thus made. In case of poor ground being met with, it is, if of larger dimensions, left standing and allowed to follow the surface on its downward course, while the small bunches of rock are removed to the foot, or hanging wall sides of the deposit. Here they are out of the way and save the cost of raising to the surface and tramping out to the rock pile. By this process practically all of the ore can be removed and at a minimum cost. But very little timber is used in the underground workings as all the drifts and cross-cuts are carried as narrow as possible and it is only when very soft ground is cut that timbering is found necessary.

The ore body has a length on this property of about 900 feet, and would possibly average seventy-five feet in width. It is not at all regular and in places it is not over fifteen feet wide and again a cross-cut will give it a width of 150 feet. (See fig. 15.) The foot and hanging walls are both plainly marked and seem to be of about the same kind of rock, commonly known as greenstone. West of the open cut and of shaft No. 1 the green rock outcrops in several places and either forms a crossing, cutting out the ore in this direction or turns it toward the south. The former theory seems to be the most plausible one, however, and the one which stands in favor among the mine operators. Two levels are now being opened up below those that have thus far been worked.

All the hoisting is done by four drums, requiring but two brakemen on a shift to handle the four cages. These drums are six feet in diameter and are made by Webster, Camp & Lane of Chicago. This plant is operated by one of E. P. Allis' double engines of the Corliss pattern, having cylinders 18x48 inches. (See plate XXIX.) With this plant during the past twelve months over 350,000 tons of ore have been raised. This is a better record than can be shown by any other plant in the region for the same length of time. In the same building an Allis compound compressor furnishes air for the operation of eight power-drills. (See plate XX,A.) This machine has a 17x36 inch live steam

cylinder and a 24x36 inch cold steam end, and air cylinders 15x36 inches. An Allis feed water heater furnishes water to the boilers, which are located in another part of the building. The boilers are of the return-flue pattern, 6 feet by 18 feet, and develop about 125 horse power each. These boilers, of which there are three, form one battery and can be used together or individually as necessity requires. Ordinarily two boilers are sufficient to furnish steam for the pumps in No. 1 shaft and the engines above described. Near No. 2 shaft a 4x16 ft. boiler and two smaller furnish steam for the pumps in No. 2 shaft. These pumps are of a special pattern, having No. 10 water ends and No. 11 steam ends. This style of water pump has been found to be the most economical, and is in general use at many of the mines. The company has a private electric light plant consisting of an eighteen-arc-light Brush dynamo, propelled by a Ball 11x10 inch engine, and besides furnishing light for all of the shaft houses and ore pockets, etc, around the mine, one of the large general stores in the town is illuminated. In looking over this property, the fact impresses itself on the observer that the managers are thorough mining men and know how to operate a mine. Everything is in its place, the machinery is well kept, and all the buildings well suited for the various duties for which they are designed, and the amount of ore mined and shipped gives evidence that the underground work is well looked after. This property is operated by the Minnesota Exploration Company, with Joseph Sellwood general manager, Jno. Pengilly superintendent, and Capt. Scadden as mining captain. One of the many interesting features of this mine is the fact that it occupies only forty acres, and the ore is taken from half of that forty.

The Pioneer mine, under the direction of Superintendent McQuade, has two shafts, sunk on the south side of the ore in what is called the foot wall, one 200 and the other 175 feet deep. The deeper one has three levels; the first is down about 60 feet, the next 75 feet lower, and the last 75 feet lower still. There has not yet been any working east and west on the first floor. On the second level there is simply a cross-cut to the ore, and but little ore has been taken out. On the third floor it is the same. The cross-cuts increase in length downward, showing a dip north. On the surface the ore is about 75 feet from the shaft, and at the bottom, 200 feet down, it is about 125 feet from the shaft. This is No. 2 shaft and is sunk all the way in broken jasper. The greenstone begins to appear in the foot wall at the bottom, but at the surface was 75 feet south from the shaft. No. 1 shaft has been so far in a "broken

up jasper and paint rock." This has two floors, one down 100 feet and the other 175 feet. On the first floor the ore was too narrow to work and on the second floor the mining has progressed west about 75 feet, and is now being pushed upward on the ore toward the first floor.

The history of this mine since ore was first discovered in it has shown that the mineral has been found in bunches. In places these deposits would be of fairly large dimensions and in others hardly large enough to pay for their removal, showing conclusively that the formation was in an unsettled state and that it would become more regular as depth was attained. The company is convinced of this fact and intend to sink the shafts deeper this coming winter, 1890-91, and in the meantime to remove all the ore that is opened up and place it in the stock piles.

The mine is well equipped with all the machinery necessary for carrying on their work. In the engine house an 80-horse power boiler, bearing the mark of Gogebic boiler works, Duluth, furnishes steam power for three pumps and the hoisting apparatus, consisting of a double four-foot drum hoist of the Marinette iron works manufacture. The engine house, blacksmith shop, "dry" and office are well built, comfortable structures and dressed in a neat coat of paint, presenting a creditable appearance.

During the past two seasons there have been shipped from the property 15,116 tons of high grade Bessemer hematite; of this amount 12,016 tons should be credited to this season's output.

The mode of mining employed here is not materially different from that of any of the other range mines. The nearly perpendicular character of the formation makes a vertical shaft the most practicable, and here in both the shafts cages are employed. The ore is shoveled into the tram cars from the drift, cross-cut or room down in the mine, pushed out onto the cage at the shaft, hoisted to the surface, trammed out to the end of the trestle, and dumped in the stock pile. The trestle running from No. 1 shaft house is elevated to a height of about thirty feet above the ground and is about 300 feet long, giving ample room beneath for a large stock pile. No. 2 is not as well arranged for stocking purposes, but a new and larger shaft house is designed and will probably be built this fall or winter. Other improvements are contemplated, among which, and probably the most important, is the sinking of a shaft on the western end of the property. This shaft will be located about 500 paces north of the section line and about 100 paces or 265 feet east of the Chandler line. Between No. 2 shaft and the west boundary line of the property, a distance of 1,600 feet, the ground is practi-

cally unexplored, and it is reasonable to suppose that valuable deposits of ore exist there, and will be opened by the new shaft. A diamond-drill hole was put down a short distance north of the location of this shaft and passed through some forty feet of clean ore. There is but little doubt that the Pioneer mine will, in the near future, develop into one of the valuable range properties.

The Zenith mine, next east of the Chandler, has been employed wholly in exploratory and dead-work—test-pitting, shaft-sinking and diamond-drilling.

As at most all of the other properties now being explored on the range considerable work in the line of running trenches and digging test-pits was done on what is known as the Zenith property prior to the date of the present company's taking possession. Just what this labor amounted to in the way of determining the value of the property or the ~~location~~ ^{length} of the ore vein is not known, but judging from the appearance of the rock from these workings seen in the dump piles, nothing but the jasper "cappings" was encountered.

Shaft No. 1, or the first one put down by the present company, measures about 6x9 feet inside, and is located 727 paces north, and 750 paces west of the section corner. This shaft is vertical, and located in jasper and other rock, the first fifty feet being sunk in the "capping" and soap rock, and the remaining twenty feet in a good variety of ore. At the depth of fifty feet a cross-cut to the north found the ore to have a width of fourteen feet, and a similar one from the bottom gave the deposit a width of nearly twenty-four feet, showing that the body is widening out as depth is attained. A drift has been driven west for a distance of thirty feet, and a cross-cut started south to connect with the working shaft for the purpose of ventilation.

Shaft No. 2 is also vertical, being carried down 7x14½ feet, inside measurement. This is to be a two-cage shaft, and is being sunk in the foot wall greenstone. Its present depth is forty-eight feet, and up to the time of this writing, all of the hoisting has been done with a windlass. The location is 710 paces north, and 760 paces west, or about 30 feet west and 46 feet south of No. 1. A Bullock diamond drill is being used on the property and has been the means of proving up the value of the eighty, as much, if not more, than the shafts just described. The hole now being worked is located 687 paces west and 850 paces north of the southeast corner, or about 370 feet north of No. 2 shaft and 190 feet east. The drill rods were given a pitch of 45 degrees to the south and the first 105

feet was drilled in jasper when about 6 feet of ore and soaprock was cut. The next 91 feet showed ore and jasper mixed, the major portion being ore; during the following 67 feet of drilling the core barrel brought up clean ore, then came 17 feet of ore and jasper and at the bottom 325 feet from the surface the drill appears to be cutting greenstone. After finishing this hole the drill will be moved 400 feet further west and 100 feet north.

Until recently (October, 1890,) no surface improvements of any kind were made on this property, but at present a large force of carpenters and mechanics of various kinds is employed on buildings for numerous purposes and other surface work. An office and warehouse combined and a blacksmith shop and "dry" are already occupied; a little farther east a boarding house 26x76 feet, two stories high, and across the county road a barn of ample size are fast nearing completion. Back on the foot-wall, between the west line of the property and No. 2 shaft a large 100-horse power boiler of the Iron Bay company's make is being bricked in, and close to it the foundation for a hoist is being laid. This machinery also comes from the Iron Bay Co., and is one of their double five foot drum-plants having 12x16 inch duplex engines. Over this outfit will be erected two buildings 28x50 feet and 20x40 feet respectively. A force of fifty men is at present employed by the company under the charge of Capt. Nick Cowling.

Still further east are several other workings and valuable iron properties, but none have shipped any ore. The railroad has not been extended to them, but probably will be in the near future.

The *Anderson Iron Company* has commenced work about a mile southwest from Ely, and a vertical shaft is being sunk (on the N. $\frac{1}{2}$, N. W. $\frac{1}{4}$ and S. E. $\frac{1}{4}$ N. W. $\frac{1}{4}$ sec. 4, 62-12,) but has not yet (October, 1890,) reached the rock. Several trenches and test-pits have been dug, and they show very nearly the same indications of ore as were encountered at first at the Chandler mine—viz: red earth, occasional clean soft hematite lumps and some high grade hard ore nodules. It seems quite likely that the ore body of which the owners are in search, lies somewhat further north, and will be found by drifting from the shaft in that direction.

The machinery on the ground consists of a small portable hoist, a No. 4 steam pump and about a 25 horse-power locomotive fire-box boiler. A force of about twelve men is employed here and suitable camps have recently been erected for their accommodation. A boiler and engine house and blacksmith shop complete the surface improvements.

At this place several other reputed iron properties are adjacent, owned by Messrs. James, Camp and Rouchleau, which again are adjacent to the Lockhart location which adjoins the Chandler. In general the region is swampy, comprising two or more parallel valleys, and the ore is supposed by Mr. Camp not to be a part of the Chandler ore body, nor associated with it, but to run E-NE toward section 25. These valleys are separated by ridges of graywacke-greenstone which are nearly continuous and rise from 20 to 30 feet above the valleys. Most of the pits and trenches show mixed green and red slate, or schist, (being a condition of the greenstone) with varying amounts of hematite mingled with chalcedonic silica. Some of the pits, which were full of water at the time of the examination but which could be partially judged of by the dumping, showed plainly a soft, clean hematite in considerable quantity, and judging by this the ore body seems to be extended over a width of several hundred feet, including interruptions of rocky strata. The ore is entirely brecciated, resembling that from the Chandler mine.

There is, in this same region, a narrow magnetic belt which is so marked that on crossing it the dip needle stands vertical over a space of a few (8 or 10) feet. This ore is represented by No. 1613.* This belt has been traced out by Mr. Camp for about a mile. It winds about and across this land. A shaft was sunk to it. The ore is apparently also graphitic. It is simply a part of the same formation that the hematite is in and stands in thin, vertical, irregular jaspilitic sheets. One sample (1619) showing a loadstone polarity, was stated by Mr. Camp to have been obtained from this magnetite deposit. The peculiarity of this is that its color of streak is reddish, not black, indicating a magnetic hematite.

The Stone mine is at Mesaba, on the Duluth and Iron Range railroad—Mallmann's original working.† It is now under charge of Capt. Bice, who has sunk one shaft to about 120 feet. The last rock thrown out is that mongrel, siliceous, chalcedonic mixture, or "feldspathic rock" which is characteristic of the Taconic (Animike) in this region, and which might be called a variable quartzite, lying above the main portion of the Pewabic quartzite.

The Mallmann mine proper is on NE $\frac{1}{4}$ of section 11, township 59, range 14, in the place where Prof. Chester made some examination for iron about ten years ago (See the eleventh annual report). A line of railroad levels has just been run (October, 1890,) from

*This magnetic character is known at the Eaton-Merritt property four miles east of Ely, and seems to increase further east. It prevails in T. 63-9. A similar magnetic belt occurs at Tower, running through the swampy ground between Tower and Soudan, and was penetrated by drill GG, at a depth of 290 feet from the surface.

† See the eighteenth annual report, page 7.

Mesaba station, which is on SW $\frac{1}{4}$ of section 21, township 59, range 14, to this mine, preparatory to extending the track for the shipment of ore. The station is 909 feet above lake Superior. The highest point found was near the mine, (at station 199) and is 1,141 feet above lake Superior.

This mine is in the Taconic, and presents the characters of the mines on the Gogebic range in Michigan and Wisconsin. The rocks dip southeast conspicuously, about 30 degrees. There is a foot wall of quartzite (the Pewabic quartzite), and an overlying wall of black slates.* No green-stone dykes are known in the vicinity, but not enough is known yet to warrant a general statement of their non-existence. The ore is hematite, vesicular, or soft, and is plainly the bedded formation, showing all the flexures and variations in texture and dip that the enclosing rocks show. It is rather allied in its lithological affinities, as shown by the encroaching impurities, with the quartzite which underlies, being in that part of the quartzite (the upper part) which elsewhere has been seen to be hematitic and rotting or rusty, or magnetic. The underlying quartzite, toward the top, and especially where it begins to hold some ore, is chalcedonic quite noticeably.

The working here has not yet been extensive, but enough has been done to disclose the existence of a large and valuable bed of hematite. There is a vertical shaft 60 feet deep, the last thirty of which, as stated by the owners, are in ore. Here it struck the foot wall. A cross-cut south was then made 92 feet, the last 85 feet of which were in good shipping ore. Other shafts and pits show the ore at a depth of 20 to 25 feet below the surface.

The interesting geological fact about this locality is not so much the opening up of a new field, and demonstration of the iron-bearing quality of the Taconic on the north side of lake Superior in such light that it seems likely to rival, when exploited, the same on the south side, but rather the fact that here the graywacke-greenstone of the Keewatin, identical with that seen at Ely, is found in immediate proximity standing vertical, or presenting shapeless knobs such as characterize it south of Long lake. Here it embraces the so-called "silver" vein to which Prof. Chester referred in his report† in 1883, the enclosing rock being a rather fine-grained.

*The thickness of the black slates is not known, but in sec. 34 (NW $\frac{1}{4}$), 59-14, near the northwest corner of the section, Mr. E. J. Longyear drilled in them 800 feet and did not penetrate through them.

† See the eleventh annual report, p. 159. The writer re-visited and looked again over the same old dump material at this "silver" pit, as in 1878. The rock was before called quartzite, and samples brought away are quartzite (442). Chester also speaks of the quartz vein cutting horizontal beds of quartzite. But at the recent visit a cursory examination showed some of the rock to be a greenish schist like the Keewatin. This may have come from the Keewatin which may have been reached at the bottom of the pit.

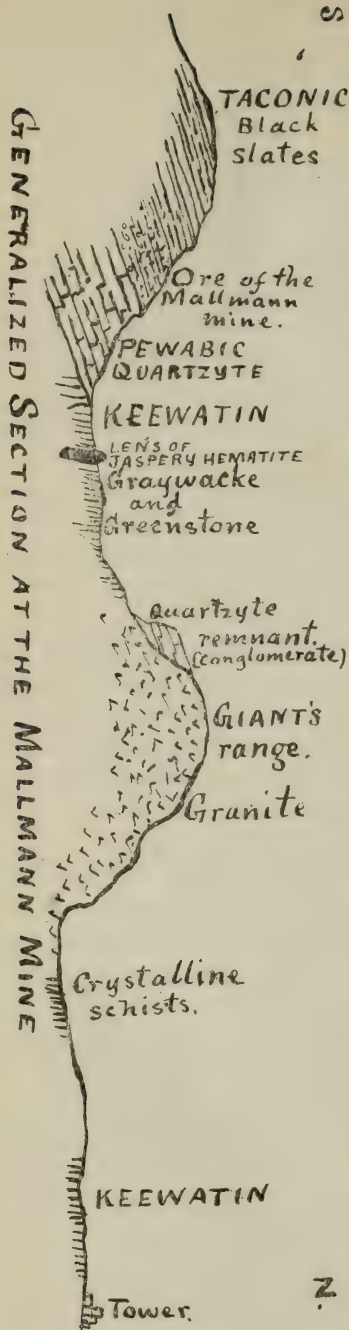


FIG. 26. -Generalized section at the Mallmann mine.

greenish, somewhat slaty graywacke showing evident sedimentary structure more perfectly than most of the graywacke about here. The interest of this Keewatin locality is increased by the existence of promising iron deposits, a jaspery hematite, near the center of section 11, which rises 10 to 15 feet in an isolated low ridge running about 15 rods. It is surrounded by Keewatin greenstone, and the structure is approximately vertical. Prof. Chester also made reference to this in his report, regarding it an anomalous occurrence in the midst of a country of nearly horizontal magnetitic quartz. It is scarcely necessary to say that this jaspery ridge of hematite has nothing to do with the ore of the Mallmann mine near which it occurs, but has its alliances with the ore mined at Tower. The adjoining diagram shows the geological relations of these two ore masses, and strengthens the intimation that, as already stated in this bulletin, similar contrariety and variety occur in the two formations at Negaunee, Mich. It is highly necessary, in any future working that may be conducted on the Mesabi range in the exploitation of the iron ores, that these two formations be kept distinct, since the ores occur in different relations to the enclosing rocks, and will require different methods of

The McComber mine is situated at Armstrong lake, about midway between Tower and Ely. Some exploratory work with a diamond

drill, and otherwise, has been carried on here for a few years. Mr. McComber states that the drill passed through good ore 12 feet and 18 feet thick. His shaft, which is 60 feet deep, is now having a drift made to the ore. He has already taken out about 300 tons of high grade ore, and the prospect is that it will ship several thousand tons in the season of 1891.

The *Diamond mine* is at the extreme western end of the Mesabi range in sec. 15, 56-24, and in the same formation, as well as in the same stratigraphic position, as the Mallmann mine described above, and exhibits the same lithological characters. There has not yet been found here, however, any portion of the Keewatin on the south side of the Giant's range, and it is presumed that at that place the granite continues southward below the Pewabic quartzite. Some account of this mine was given in the eighteenth annual report, pp. 15-19, based on a visit to that place in 1888. At that time sufficient information was not at hand to establish the relation of the Pewabic quartzite to the black slates of the Taconic, and that point was left in doubt. Since then the slates have been found to lie above the quartzite. At that time three shafts had been sunk to the ore, the deepest being 47 feet. No great amount of merchantable ore had yet been found, but since then it is reported that ore of good quality and in large quantity has been

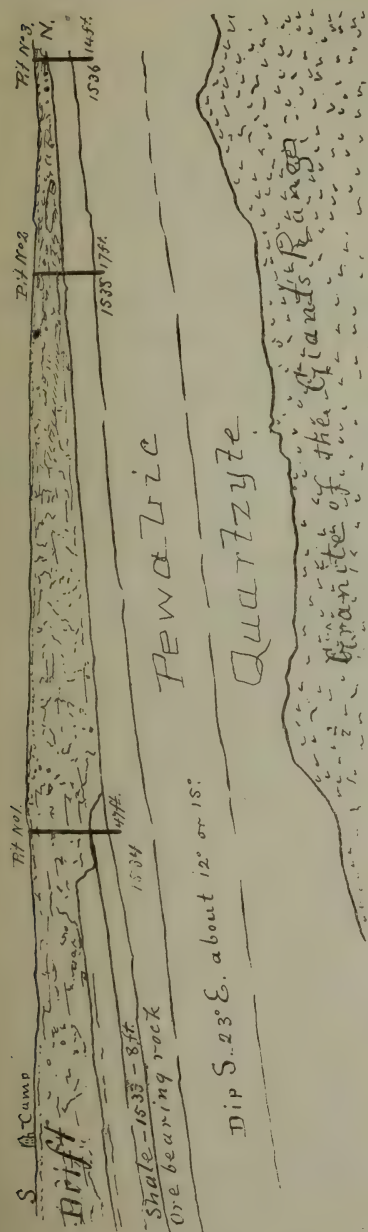


FIG. 26.—North and south section through the Diamond mine.

found in that region. The Duluth and Winnipeg railroad runs within about ten miles of this mine, but there is no branch yet built to it. The following section, figure 26, north and south through this mine shows the geological relations.

At numerous other points considerable exploratory work has been done both on the Mesabi and on the Vermilion range, and some of these other locations might be classed as mines.

The Mountain Iron Company, on S. $\frac{1}{2}$, S. E. $\frac{1}{4}$, and S. $\frac{1}{2}$ S. W. $\frac{1}{4}$ sec. 34, 59-18, have a diamond drill at work, in the Keewatin. Ore that affords 64 per cent. metallic iron was met at the depth of 38 feet.

□ J. M. Longyear has been working a diamond drill on the N. W. $\frac{1}{4}$ of sec. 34, 59-14, near the southwest corner, also at a point further north, and in the latter place is reported to have ore similar to that in the Stone mine.

Langdon, Conkey and Warren (of Minneapolis) have some working on sections 31 and 33, 64-9.

There are numerous other places where work has been done, sometimes at little expense, and sometimes involving thousands of dollars. But as they are either unknown as to exact location, or have resulted in nothing of economic importance there is no need of enumerating them. On the accompanying geological map all known localities of iron ore are denoted by a bright red color.

PART III.

TRANSPORTATION OF MINNESOTA ORE.

All of the product of the Minnesota iron mines is shipped in the first instance by rail to Two Harbors (formerly known as Agate bay) on the north shore of lake Superior. It is then loaded on barges which carry it by the waters of lake Superior, St. Mary's river, lake Huron, St. Clair river, lake St. Clair, Detroit river and lake Erie to the lake ports of Buffalo, Cleveland and Toledo. Some of the lake Superior ores also stop at Detroit, or, passing westward on entering lake Huron through the strait of Mackinac, they follow lake Michigan to Chicago.

The Minnesota Iron Company, being the pioneer enterprise in the actual mining of these ores in Minnesota, took simultaneous measures for their transportation and their mining. By means of an auxiliary corporation, known as the Duluth and Iron Range railroad company, after the donation by the State of Minnesota of a generous grant of public land, the railroad was completed from Two Harbors to Vermilion lake in 1884, and a year or two later was extended to Duluth where it made its terminal connection with the Northern Pacific and other railroads that center at that point. The location of the road is shown on the accompanying map. Its profile of elevation is shown by plate xxxvii, extending from Duluth to Ely. The elevation of lake Superior is 602 feet above the sea. Tower Junction is 775 feet higher or 1377 feet above the sea. The ridges in which the mines are located at Soudan rise to the extreme height of about 1600 feet above the sea, but they are generally about 1550 feet above the sea. The mines are opened on their summits, and by hand-cars which run over the trestled tramways to the "docks" or "pockets", the ore, after hoisting, is conveyed to the railroad. It here descends rapidly through the pockets, or is dumped immediately into the ore-cars (compare plates xxv, xxvi and xxvii) which stand convenient near the pockets, or docks. In this operation the ore descends from fifty to one hundred feet be-

low the summits of the hills. The cars are then yarded and made into trains by the switch engines, at a level about fifty feet still lower. One of these ore-cars, when empty, is shown on plate XXXVIII. It has three compartments, the sides of which slope like a hopper toward the bottom, and they are unloaded by an arrangement which allows the bottom to drop out in the manner of a dredge-bucket.* These ore cars carry an average load of about twenty tons (their capacity being twenty-five tons) and when made up into trains the separate trains, when full, contain twenty-two cars. The powerful engines which haul these trains are from the Baldwin Locomotive works. Plate XXXIX represents one of them.

The following table shows the operations of this road for the first six years:

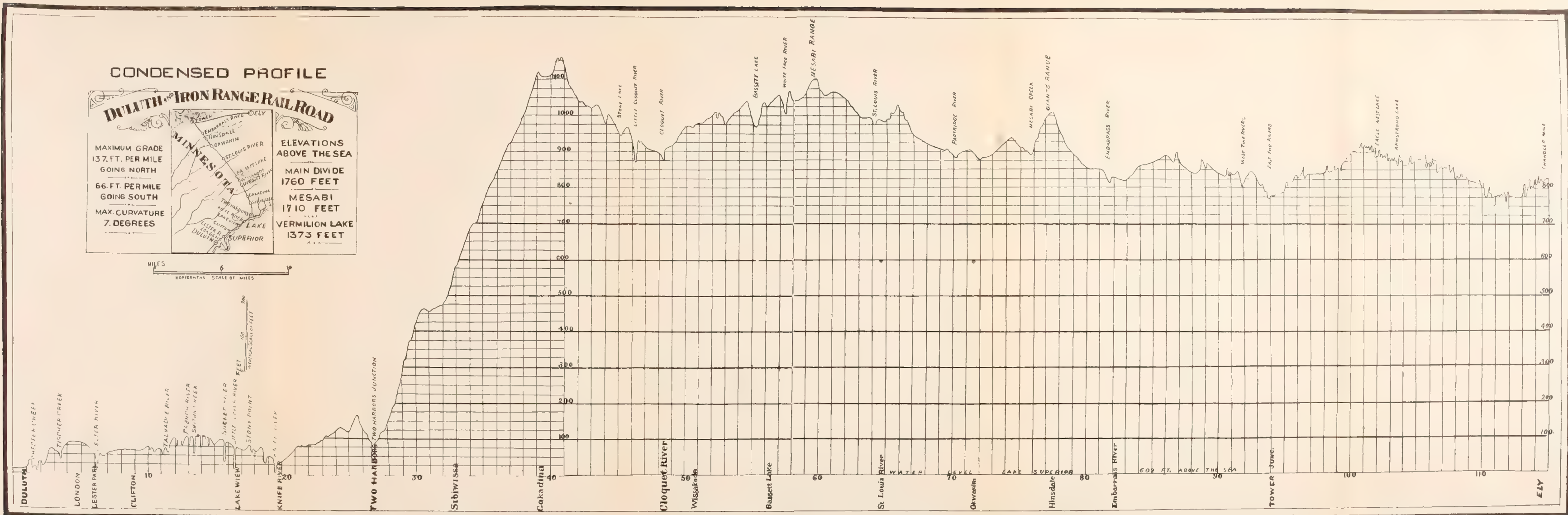
Statistics of Duluth and Iron Range Railroad.

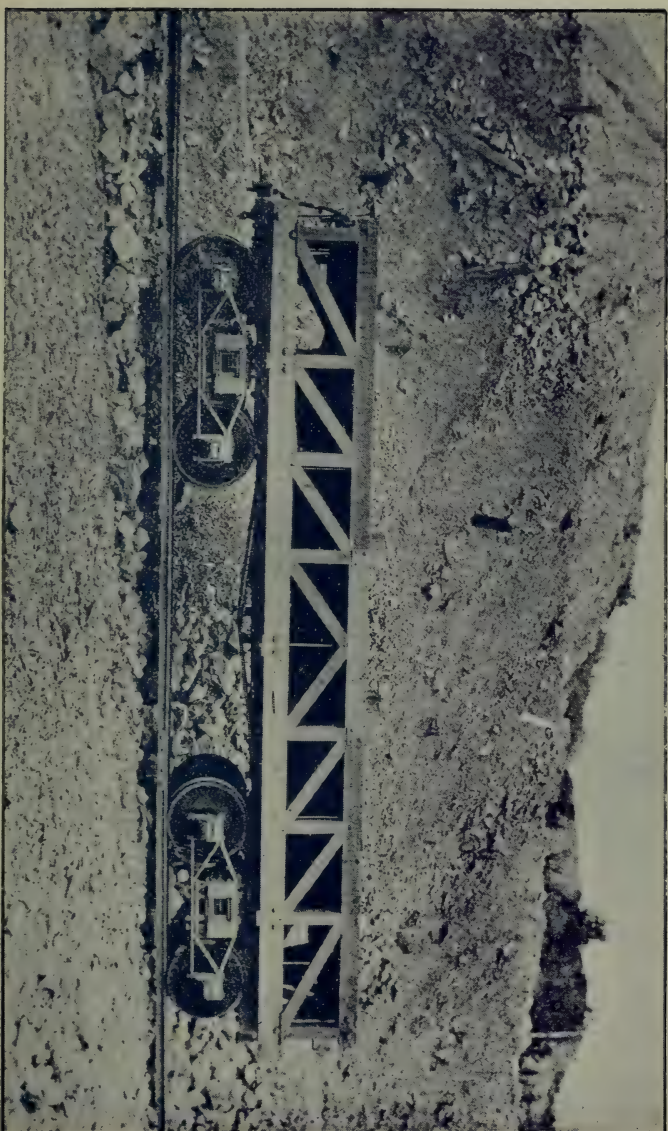
	Aug. 21 to Dec. 31, 1884	1885	1886	1887	1888	1889
L'ngth of road(miles)	60.2	60.2	97.6	96.3	118.26	115.75
Passengers carried..	3,225	4,784	6,823	33,985	70,789	102,846
Passengers carried one mile.....	193.388	280.265	418.509	1,547.732	1,679.659	2,012.189
Tons freight moved..	73,799	258,725	366,629	493,246	627,416	887,592
Tons freight moved one mile.....	4,561.581	17,582,548	24,813,017	33,150,394	42,857,084	64,838,694
<i>Earnings.</i>						
Passenger.....	\$ 9,660.30	\$ 14,463.25	\$ 20,497.28	\$ 66,203.23	\$ 65,529.91	\$ 77,368.68
Freight.....	119,896.14	258,637.54	361,410.07	512,356.97	577,568.60	794,559.15
Mail and Express....	300.00	450.00	3,113.33	3,188.00	4,878.92	2,480.04
Miscellaneous.....	4,988.12	858.66	1,590.35	282.30	2,120.17	7,796.81
<i>Total.....</i>	<i>\$ 134,853.65</i>	<i>\$ 247,409.45</i>	<i>\$ 386,521.03</i>	<i>\$ 582,030.50</i>	<i>\$ 650,088.60</i>	<i>\$ 886,518.76</i>
<i>Expenses.</i>						
Maintenance of way	\$ 15,599.17	\$ 45,432.10	\$ 36,766.97	\$ 64,586.35	\$ 83,129.87	\$ 96,694.41
Rolling stock.....	6,589.09	15,321.79	20,374.76	103,999.30	156,238.18	112,359.66
Transportation.....	27,795.44	53,856.08	81,560.64	53,649.67	78,190.12	234,473.88
Miscellaneous.....	16,029.47	37,155.12	40,894.41	61,958.56	61,475.70	50,891.16
<i>Total.....</i>	<i>\$ 66,013.17</i>	<i>\$ 152,165.09</i>	<i>\$ 179,606.78</i>	<i>\$ 284,193.88</i>	<i>\$ 379,033.87</i>	<i>\$ 494,019.11</i>
Per cent.....	51.04	45.55	53.79	51.17	41.69	44.27
Net earnings.....	\$ 68,840.48	\$ 122,244.26	\$ 206,914.25	\$ 297,836.62	\$ 271,054.73	\$ 393,499.65
		Deficit				
Surplus.....	38,199.04	17,921.97	61,834.15	132,602.83	42,464.16	135,515.01
Cost of construction and equipment (steel rails, 61 lbs. per yard).....	2,531,507.23	2,436,282.71	2,982,101.28	7,170,219.26	8,221,068.36	9,247,152.04
<i>Train Mileage.</i>						
Passenger trains....		35,585	40,256	78,953	111,221	110,735
Freight trains.....		94,388	129,745	194,414	241,386	315,155
<i>Total.....</i>		<i>129,971</i>	<i>170,001</i>	<i>273,367</i>	<i>400,754</i>	<i>502,687</i>

Duluth and Iron Range R. R.

Chartered Dec. 21, 1874. State swamp-land grant, ten sections to the mile. 96.3 miles completed December, 1886. Road opened from Two Harbors to Tower (67.6 miles) Aug. 21, 1884; from Tower to Ely (21 miles) Oct. 1, 1888.

*These cars are manufactured by three different firms: The Lafayette Car Works, Lafayette, Ind., Haskell & Barker Car Co., Michigan City, Ind., and the Wells-French Car company. Chicago, Ill. They do not differ materially in style.





ORE CAR, DULUTH & IRON RANGE R. R., TOWER.



LOCOMOTIVE OF THE ORE TRAINS, DULUTH & IRON RANGE RAILWAY. P. 208

Rolling stock in use.	Dec. 31, 1888.	June 30, 1889.
Locomotive engines.....	27	34
Passenger cars.....	7	10
Combination cars.....	2	3
Baggage, mail and express.....	2	2
Caboose, &c.....	15	20
Box cars.....	50	50
Stock cars.....	2	2
Platform cars.....	304	303
Coal cars.....	15	15
Ore cars.....	480	738
Total.....	862	1143*

*Transportation of iron ore.**Freight rates.*

From Ely to Two Harbors, per ton.....	\$1.00
From Tower to Two Harbors, per ton.....	.75
From Two Harbors to Cleveland, per ton.....	1.35
From Ashland to Cleveland, per ton.....	1.25
From Marquette to Cleveland, per ton.....	1.25
From Escanaba to Cleveland, per ton.....	1.10

Dockage charges, (not chargeable against the ore.)

At Two Harbors.....	\$.04
At Ashland.....	.04
At Marquette.....	.04
At Escanaba.....	.04
At Cleveland.....	.04

Unloading at Cleveland (paid by the vessel)..... .18*Freight rates by rail:*

From Ely to Two Harbors, per ton.....	\$1.00
From Tower to Two Harbors, per ton.....	.75
Ishpeming or Negaunee to Marquette, per ton.....	...
Ishpeming or Negaunee to Escanaba, per ton.....	.70
Hurley to Ashland, per ton.....	.70

Facilities at Two Harbors. There are two large ore-docks at Two Harbors. The dock No. 1 was erected in the summer of 1884, and is 1,200 feet front, extending into Agate bay. Its north side has a pocket frontage of 1,000 feet, and the south side a frontage of 925 feet, devoted to loading of cargoes. The total aggregate frontage is 2,400 feet, with a 1,925-foot front devoted to the loading of vessels. Within this frontage, there are on the north side of the dock 88 pockets, and 74 on the opposite front, giving a total of 162 pockets, having a total capacity of 16,000 tons. The water adjoining is from 17 to 21 feet in depth, and the dock itself is about 47 feet wide by about 50 feet high.

The No. 2 dock has a total length of 1,200 feet, and a total water front of 1,925 feet, of which 1,625 feet is devoted to pocket room, the north side having 600 feet front and 53 pockets, while the south front has 1,025 feet provided with 88 pockets. The gross frontage for this side is 1,200 feet, and for the north side 725 feet,

*Poor's manual of railroads.

making a total of 1,925 feet. The dock has 141 pockets, of 1,800 tons total capacity. This being the more recent dock, it is provided with larger pockets. It was constructed in 1885.

It is proposed to erect a third dock, south of the No. 1 structure, at some future time, placing the new one, or the No. 3 dock, some 200 feet away. It is to be constructed of iron and steel, and will increase the frontage devoted to the ore business some 2,100 feet, and the tonnage all of 20,000 tons, or probably 25,000 tons, which would then show for Two Harbors a frontage of 5,650 feet, and a tonnage capacity of 59,000 tons.

The present breakwater is 550 feet long and 1,275 feet from the end of dock No. 1 and 1,270 feet from the end of the proposed or No. 3 dock.

There is also shown on the map a projected breakwater in line with the present one, from the opposite side of Agate bay, which is to be 1,025 feet long, leaving an entrance between them of 1,725 feet, which, with the 550 feet of the present one and the distance of 120 feet that it is away from shore, makes a total of 3,420 feet, the width of the bay at this point. The bay, when the proposed breakwater is completed, will include all of one square mile of area. The end of the proposed structure is 1,325 feet from the dock No. 1.

Two general merchandise docks are maintained, one of 404 feet length and a second of 379 feet long, having between them a slip of 400 feet long by 100 feet wide—the docks themselves being 50 feet wide. The west dock has a frontage of 735 feet and the east one, used as a coal dock since 1888, has a frontage of 475 feet, upon which there are employed three rotary hoists in conjunction with hoppers overhead, which admit of loading direct to railroad cars or of conveying to the large storage space of 125 feet by 425 feet. They can handle 800 tons of coal per day of ten hours with three rotary hoists.

The lake carriers. The capacity of the canal at Sault St. Marie limits the size of the cargoes of some of the larger boats that carry lake Superior ore, and in general larger cargoes leave the docks at Escanaba (a lake Michigan port which is the southward outlet for ore from Negaunee) than any of the lake Superior ports. The following, however, cleared from Two Harbors the third week in October, 1890: Manola, 2,343 gross tons; Matoa, 2,336 gross tons; Maruba, 2,311 tons; Mariska, 2,281 tons; J. C. Lockwood, 2,179 tons; Alex Nimick, 2,105 tons; Gladstone, 1,971 tons; Siberia, 1,898 tons; Hesper, 1,881 tons; R. P. Flower, 1,776 tons; J. S. Fay, 1,319 tons and D. P. Rhodes, 1,529 tons. These are all large

lake Superior loads, but one of the "McDougal boats," barge 107, carried 2,698 gross tons through the canal a short time before.

By far the greater portion of the ore output is got to market by these large lake carriers, whose owners are often interested in the ores they carry, and in the mines that produce them. They have season contracts, at rates that enable them to make somewhat regular trips, or they are required to take the output under such restrictions that their rates are susceptible of being maintained against competition of "wild" freighters. This gives greater stability to the markets and security to the producer, although, in some exceptional cases the rates of the "wild" freighters are less.

Future transportation routes. In the event of the development of our iron ore industry further west, say between Duluth and the Mississippi river, whether it be in the conversion of ore to steel by charcoal process or not, there can be no doubt that the Mississippi river itself will become the chief avenue of transportation, and that the coals of Iowa and Illinois will be the objective points. There is no cheaper way of transporting freight like iron ore than by water, and there are no cheaper water-ways than rivers and canals. The route from Grand Rapids on the Mississippi by river to points near the coal fields of Illinois and Iowa, would compete successfully with that by lake from Two Harbors to Cleveland. The Mississippi is navigable without improvement between Grand Rapids and Aitkin, and between St. Paul and the gulf of Mexico. There are rapids and water-falls between St. Paul and Aitkin where locks and canals would have to be constructed.

Market prices of iron ore.

There is from year to year a fluctuation in the market prices of iron ore, due to causes that are similar to those that modify the prices of other commodities, viz: Depression in the general financial conditions, over-production, or scarcity of ready ore at epochs when it is specially demanded. Sometimes the element of lake transportation has operated to enhance the value of ore at Cleveland, there having been insufficient lake tonnage, necessitating shipment all the way by railroad, and sometimes dockage facilities have been wanting. Prices in 1889 were very low, almost the lowest ever known, but in 1890 they were from \$.50 to \$1.00 per ton higher. The best lake Superior ore sold, in 1890, from \$6.00 to \$7.25 per ton. The Bessemer hematites generally reached \$6.50 per ton. The standard, hard, non-Bessemer hematites, such as the Vermilion grade of the Minnesota Iron Company, sold at \$6.00 per ton. Soft, non-Bessemer ores, with from 59 to 60 per cent. of iron, sold for \$4.25 to \$4.50 per ton.

Profits.

The net profit of a successful iron mine is often very great, in proportion to the money invested. There is a large amount of money lost, it is true, in fruitless investigation, but it is small compared to the income from the successful mines. It is impossible to ascertain the precise average cost of mining iron ore per ton. The mine owners are chary about divulging the statistics that indicate their profits. Some facts, however, which are known and others which may be estimated, afford us an approximation to the result of a year's work. It was attempted to ascertain, from official sources, the average cost of mining a ton of iron ore, and to distribute this cost, at the respective mining points, among the items that go to make the cost—such as explosives, labor, machinery and timber, repairs, etc., but the attempt had to be abandoned. It is only when, by law, mining companies and all similar corporations are required to keep open books, showing their expenses and receipts, that a reliable statement can be made of the profits of mining iron ore.

Some of the soft Bessemer hematites on the Gogebic range have been mined at a cost of about \$.75 per ton in large quantities, but that was when the ore was so near the surface and so abundant that it required but little more than the excavation and the shoveling of the product into the cars, which, in this case, were run even into the side-hill where the ore was found. In general, however, the cost of mining the soft ores is much greater. At Ely it has been estimated at \$.90 to \$1.00 by some of the officers not interested in the Chandler mine, but it probably is somewhat greater, and may be supposed to not exceed \$1.25 per ton. This, of course, does not include transportation from the mine.

At Tower, the expense of mining the harder ore is correspondingly greater, and at the same time the company has entered upon extensive and expensive improvements, and on investigations by the use of the diamond-drill in order to learn the extent and the position of the ore bodies. Proportionately the net profits are less at Tower than at Ely. Estimates of the cost per ton at Tower, by non-interested parties, placed it at \$1.55 to \$1.65, but we have reason to believe it is nearly \$2.00, allowance being made for all improvements and explorations, and for depreciation of the property, the life of the plant being considered fifteen years.

The net profits, based on these figures, and allowing for cost of transportation to Cleveland, amount to about one million dollars for the mines at Ely, since they were opened in 1888, and about five millions of dollars for the mines at Tower since 1884.

PART IV.

ORIGIN OF THE ORES OF IRON.

Growth of theories—An examination of the literature giving the different views advanced during the last half-century to account for the formation and accumulation of iron ore deposits reveals the fact that there has been a gradual evolutionary change in the opinions of geologists. With the growth of geological science and with improved methods of research and the consequent increase in particular and exact knowledge of the natural forces at play in the destruction and construction of rocks and minerals, there has been an accompanying revision of ideas formerly held, some of which now appear to us more or less crude and unsatisfactory. This revised opinion is not universal among geologists as yet; but the majority of recent writers and the preponderance of opinion seem to have been tending toward results that were very little anticipated thirty or forty years ago.

When the facts of the universal distribution of iron and of the many different ways in which it is acted upon by all the transmuting agencies which continually surround and involve it are taken into consideration, the wonder is not that there is such a complexity of theories and such conflict of opinion, but rather that there is so large an agreement as there is, and so few theories advanced to account for its accumulation in large deposits. It is astonishing, however, to any one who has noticed the many ways in which iron oxides are produced and transported from place to place, to find reputable and learned geologists advocating in their writings one single method of origination and accumulation for all ores of whatever age, or however varied in chemical composition and physical characters. Yet such will be seen to be the case in several remarkable instances.

Before the various phenomena of metamorphism had become generally understood and while plutonic forces were assigned on every hand as the cause of all things not easily explicable otherwise, it was natural enough that deposits of iron ore should have

been universally considered veins, connected at an unknown depth with a parent mass in the interior of the earth. But when in a thousand cases these so-called veins had been mined out and proven to be isolated, lenticular masses, without any deep-seated connection, and when we consider that the oxide of iron, if fused with the accompanying "gangue," would have produced anything but deposits of good iron ore, we should expect that no geologist in recent times would have the rashness to revive and reassert the old idea of igneous *veins* composed of hematite or magnetite, with a gangue of jasper or acidic feldspathic rocks; yet there are several notable examples of just such wild speculation and argumentation. The tendency of geologists in general, however, has been away from the igneous and sublimation theories, towards those based on sedimentary or combined chemical and sedimentary forces. It is true that some of the very early geologists, both in this country and in Europe, advocated a sedimentary origin for some or all of the iron ores; but they were rare exceptions to the general rule and their views met with very little favor.

Whereas, in the seventeenth century, no distinction was made by those who attempted an explanation of the existence of ore deposits, between those of iron and those of gold or silver, or lead, or any other kind of ore, there has been a process of differentiation in the last two hundred years similar to that which has been witnessed in nearly all cases of continued investigation. There has been a specialization in observation which has resulted in discrimination among the various kinds of ores. Some were found to present different physical structure and surroundings. Some were differently constituted chemically, and differently allied to the rocks in which they exist. An important distinction was made when iron ores were considered separately from the other metals, and were investigated independently. Another important distinction was made when the metalliferous fissure-veins were distinguished from metal-bearing strata or isolated lodes or lenses. There has been a continual descent from the complex to the simple and single, both in general geological conception and observation, and in the theory of ore-origin. The general complex idea has been, to a certain extent, separated into its single and individual components. There is need of still further specialization. Iron ores as a group cannot be lumped into one hypothesis to explain them, although there have been several notable recent efforts at that result. They must be separated from one another, and each must be investigated independently. The necessity for special examination of each iron ore deposit, or at least for each class of iron ores, whether they

be classed chemically or stratigraphically, has been recognized by some, but not by the majority of recent writers. There is nothing that the present authors desire to enforce more emphatically than this, as a result of their study.

A summary recital of the earliest views of the genesis of ore deposits will illustrate this evolutionary change.

Early views of the origin of ore deposits. In Werner's classical treatise, "A New Theory of the Formation of Veins," the various views held up to the year 1789 are mentioned and outlined. These views have been quoted by Von Cotta and Phillips in their treatises on ore deposits and by John Taylor in the Report of the British Association for 1833;* and an abstract from that one of them which is more concise and clear will be used here, without any further reference to the place where the exact language quoted may be found.

Georgius Agricola, whose real name was Bauer and whom Werner calls the father of mineralogy and of the science of mining, was the first to propound a theory of veins in his work *De Ortu Et Causis Subterraneorum* (1546.) In this, the principal agents were, water, which dissolved the enclosing rock, heat, and cold. In accordance with the state of science at that time, he considered the metals to have been formed from other substances and deposited from solution in water. He considered the then prevalent belief that lodes are of the same age as the globe itself "an opinion of the vulgar."

Utman, Elterlein, Meier, Löhneis and Barba are passed by in contempt by Werner, as they attributed the richness or poverty of veins to such absurd causes as the position of the mountains with respect to the sun, and the influence of the stars.

Rössler, who died in 1673, regarded veins as fissures previously existing in the rocks and subsequently filled with minerals.

Becher (1669) ascribes the formation of metals and minerals to subterranean vapors which penetrated the veins and produced a peculiar change in their earthy and stony constituents.

Stahl (1700) considered the lodes to have been formed in the enclosing rock at the time the world was created.

Henkel (1725) attributes the formation of ores in lodes to a peculiar exhalation produced and engendered by a "fermentation" supposed to take place in the interior of rocks. The vapors penetrated earths and rocks suitable for a matrix.

Hoffman (1738) supposes lodes to have been formed in the fissures of rocks.

*See also Geol. Cornwall, Devon and W. Somerset, De La Beche. 1839, p. 349, *et seq.*

Lazzaro Moro held the same opinion and believed them to have been filled with molten eruptive matter. This seems to have been the earliest statement of this view.

Zimmerman (1746) supposed the veins and the ores in them to have been produced by a transformation of the substance of the enclosing rocks; this alteration being assisted by certain saline substances which prepare and render the earthy matters capable of being changed into metalliferous minerals and their accompanying vein-stones.

Von Oppel (1749) explains the veins distinctly as subsequent fillings of original fissures, and thus separates them from beds and strata.

Lehmann (1753) first mentions Hoffman's hypothesis, and then adds, that the lodes are the branches and shoots of an immense deposit situated at a prodigious depth in the bowels of the earth. He compares the lodes to the branches of a tree. From this central manufactory of the metals they have made their way into the fissures in a humid and gaseous condition.

Delius (1770) considered the vein-fissures to be a consequence of the contraction caused by the drying up of the earth. The rain water penetrating the rocks dissolved the elements of the rocks and metals and conveyed them into the fissures, where by subsequent evaporation they crystallized out.

Charpentier (1778) agreed essentially with Zimmerman's theory, which he carried still further.

Baumer (1779) says: "The lodes differ in form and matter from the rocks; from various data it follows that they were formed under the ancient sea, since the out-croppings of the same are often covered with several layers of schist; and petrifications of sea-species have at times been found, as well in the geodes they contain as in the lodes themselves."

Gerhard (1781) like many others, considered the lodes to have been formed by a metamorphosis, in consequence of a kind of fermentation and decomposition caused by water and heat. He supposed further that water penetrating the country rock dissolves certain substances, and afterward passing into vein fissures there deposits the minerals which it previously held in solution. These minerals, he is of opinion, existed originally in the adjacent rocks, and have been carried in a state of aqueous solution into the fissures, where they are now found in the form of metalliferous veins.

Von Trebra (1785) ascribes the origin of metalliferous lodes mainly to the action of "putrefaction and fermentation." He appears to regard the two terms as synonymous, and subsequently

defines the latter as "the quality which, acting by insensible degrees, produces the most perfect transformation in the bowels of the earth."

Lasius (1789) considers veins to have been formed in rents produced by revolutions of nature, and these he believes to have been afterwards filled with water containing carbonic acid, which thus acquired the property of dissolving various earthy and metallic matters contained in the rocks through which they percolated. By reason of various precipitants these substances were afterwards deposited in the fissures in which they are now found. He, however, is not so clear as to whether the metallic particles were already present in the substance of the rock, or were formed in them by the action of water upon minute "metallic seeds."

Werner (1791) developed his own views on the subject at considerable length. He believed that all true veins were originally rents and were subsequently filled with mineral matter from above. Rents or fissures have been produced by various causes and at very different periods. Mountains were formed by a successive accumulation of different beds upon one another; the resulting mass was at first wet and possessed of little solidity or coherence, so that when the accumulation had attained a certain height it yielded to its own weight, sank, and cracked, or the rocks on an exposed side, as toward a valley, separated from the rest in consequence of the contraction caused by drying, or the shock of an earthquake, assisted by gravitation. "The vein-stuff arose from a wet precipitate which filled the fissures from above, that is, from a wet and mostly chemical solution, which covered the region where the rents existed, and filled the open fissures."

Although Werner claimed to be the author of the idea of the successive formation of veins and of their relative ages, it seems that an Englishman, Dr. Wm. Pryce, in a work entitled "*Mineralogia Cornubiensis*", published in 1778, had advanced the same idea at length. Dr. Anderson, Werner's translator, believes that this work was unknown to Werner, since he was so uniformly fair and just in giving every man credit for all he believed.

Werner's theory was very generally accepted and held for 25 years or more. During that time, however, various modifications or even substitutes for it were proposed.

Hutton (1795) advanced the idea of igneous injection of vein material. This theory had been briefly stated in 1740 by Lazzaro Moro, but is generally known as Hutton's theory. Hutton argued very strongly in his *Theory of the Earth*, that "Veins are of a formation subsequent to the hardening and consolidation of the strata

which they traverse, and that the crystallized and sparry structure of the substances contained in them shows that these substances must have concentered in a fluid state. This fluidity was simple, like that of fusion by heat, and not compound like that of solution in a menstruum. It is inferred that this is so from the acknowledged insolubility of the substances that fill the vein in any one menstruum, and from the total disappearance of the solvent, if there was any, it being argued that nothing but heat could have escaped from the cavities.

It is further maintained, that as the metals generally appear in veins in the form of sulphurets, the combination to which their composition is owing could only have taken place by the action of heat, and, further, that metals being also found native, to suppose that they could have even precipitated pure and uncombined from any menstruum, is to trespass against all analogy, and to maintain a physical impossibility.

It is therefore inferred that the materials which fill the mineral veins were melted by heat and forcibly injected in that state into the clefts and fissures of the strata.

The fissures must have arisen, not merely from the shrinking of the strata while they acquired hardness and solidity, but from the violence done to them when they were heaved up and elevated in the manner which the theory has laid down. Slips or heaves of veins, and of the strata inclosing them, are to be explained from the same violence which has been exerted.

The parallel coats lining the walls or sides of the vein, which are attributed by Werner and others to aqueous deposition, are ascribed to successive injections of melted matter.

Again, it is said that if veins were filled from above and by water, the materials ought to be disposed in horizontal layers across the vein." (Rep. Brit. Assoc. Adv. Sci., 1833, page 10. Taken from Prof. Playfair's "Illustrations of the Huttonian Theory of the Earth.")

Hutton's theory grew in favor with miners and geologists for many years, and about 1820 many were so extremely imbued with the igneous theory that veins of quartz and porphyry as well as beds of quartzite and limestone or marble were regarded as of eruptive origin.

On the supposition then generally held that all ore deposits were of the nature of veins or lodes connected by fissures with deeper portions of the earth, and with an imperfect knowledge of chemical affinities and of the change that takes place when iron and quartz are fused together, it is not to be wondered at that

deposits of iron ore and jasper were considered to be out-pourings of molten matter from the interior of the earth. But that this idea should have survived for nearly a century in spite of the light thrown upon the subject by practical mining and by experimental chemistry, and that it should even now be maintained by eminent geologists, is surprising to say the least, and is a good illustration of the difficulty of eradicating an erroneous idea when once it has obtained credence and acceptance in the human mind.

The theories of Gerhard, Lasius and Delius have generally been considered as containing the idea of lateral secretion or of segregation. This theory was elaborated by G. Bischof, who only applied it to true veins and not to all varieties of ore-deposits, as was originally the case.

It is thus seen that prior to the beginning of this century the four principal theories of the origin of ore bodies in general were: 1. That they were formed contemporaneously with the rocks which enclose them. 2. That they were open fissures filled by precipitation from above. 3. That they were cracks formed by upheavals and filled with injected molten matter. 4. That they were formed by lateral secretion: i. e., by deposition from waters, which percolated through the adjoining rocks and dissolved certain ingredients from them which they again deposited in the fissures.

Geologists, however, were not evenly divided in opinion among these four views. The theory of contemporaneous formation was generally discarded as early as the 16th century. Stahl is the only decided advocate of it since the beginning of the 17th century, and he maintained it only because he found so many objections to the other theories which he did not know how to explain. Among uneducated miners, however, it was and is still a common opinion. De La Beche in his *Geology of Cornwall*, (1839) says: "With a few important exceptions, the present impression among the Cornish miners seems to be that lodes are contemporaneous with the rocks in which they are found. How long this impression may have been prevalent it is difficult to ascertain; * * * Pryce, who published his *Mineralogia Cornubiensis* in 1778, makes no mention of this opinion, which, as he often cites those of his day on other subjects of the same kind, we may have expected him to have done if it prevailed to any considerable extent at his time in Cornwall." (p. 352.)

Werner's theory was satisfactory to the common mind and the casual observer for 25 or 30 years; but careful students had already discarded it as early as 1825, and in 1840 Baron Beust completely overturned it.

Hutton's theory of injection was the idea which took the strongest hold and was believed, with some few modifications, by the majority of geologists up to the middle of the present century. Von Cotta says: "When the igneous origin of many rocks, which occur as dikes, had once been recognized, many persons were inclined to consider all lodes as igneous-fluid injections. Petzhold, in his geology (1840) even attempted to maintain that as being the most recent and consequently deepest ramifications from the interior of the earth, they must necessarily be the richest in metals and have the greatest specific gravity."

In 1833 John Taylor presented a report to the British Association for the Advancement of Science upon "The present state of knowledge respecting mineral veins." After reviewing and summarizing the various theories advanced to account for their origin, he suggests that the chief difficulty with all theories up to that time was that each theory had been drawn from a limited series of observations on only one or two of the many kinds of veins, and was then supposed by their originator to apply to all mineral lodes. He thinks that no general explanation can be accepted for all ore-bodies, but that each one of the early theories may have some truth in it and may apply to one or more classes of deposits.

When this idea was fully accepted a long step forward was taken toward the right understanding of ore-bodies, and we may begin from that time to look for accurate observations and reasonable theories as to the origin of iron ore deposits, whether in beds or veins. Still, though iron ore deposits were now understood to occur in beds and irregular accumulations differing in many respects from fissure veins of gold or silver or other ores, it was yet some time before it was realized that *different kinds of iron ore* deposits may have had different origins. Consequently if one observer proved to his own satisfaction that a certain deposit of iron ore was associated with eruptive labradorite rocks and could not be separated genetically from them, he jumped immediately to the conclusion that all other accumulations of iron ore were of igneous origin; or if another observed bog iron ores in process of formation, and after great study arrived at a correct understanding of the chemical reactions between the decaying organic matter, the atmosphere, and the iron compounds, he was at once blind to any other method of the formation and accumulation of iron oxides and must put himself on record as concluding that "*both now and always iron ore is and has been accumulated by organic agency.*"

Hence we may now turn our attention exclusively to the various theories of the origin of iron ore proper. References are made in

the accompanying bibliography to papers and books in which this subject is touched upon, and where reference is not made here to the places where a certain idea is to be found, such data and often a literal quotation or a resumé of the opinions of the author referred to may be found in the bibliography.

Many different opinions have been and are still held by geologists as to the forces which have co-operated to produce deposits of iron oxide, and as to the manner in which these forces have been applied to the compounds which have been made to yield up their store of iron. In fact there have been generally two or three theories for each of the workable deposits of ore, so that a student is at a loss to know what to believe concerning the origin of any one of them.

BOG IRON ORES.

There is one class of iron ores, however, upon which geologists practically agree. That is the ore which can be observed to be in process of formation in our marshes, viz., bog ore or limonite. No one would claim an eruptive origin for such ores, because they can observe their deposition from day to day. These ores, although generally somewhat impure, are essentially hydrated peroxide of iron ($\text{Fe}_2\text{O}_3 + 3\text{H}_2\text{O}$), containing when pure, 14.42 per cent. of water and 59.9 per cent of iron. Phosphoric acid is frequently present in deleterious amount.

The general explanation given of the way in which they are formed is as follows:

Peroxide of iron (ferric oxide or hematite) is found in fine particles in all streams, lakes, ponds and marshes. It is derived from the decomposition of rocks in which iron occurs in any combination whatever; upon the decay of these rocks the atmosphere attacks the iron, and, in the absence of reducing agents, burns or oxidizes it just as any piece of metallic iron, a hammer or saw, for example, exposed for any length of time to the damp air, is oxidized, forming iron rust or ferric oxide. This iron rust, however, is disseminated through the rocks and soil in fine particles, and being insoluble in the ferric condition, would remain there but for the action of decaying organic matter, which is found in nearly all superficial percolating waters. When vegetable matter decays it undergoes a process of oxidation or combustion similar to that of the rusting iron; that is, the carbon of which the vegetable matter is composed, unites with oxygen and forms carbonic acid gas. Some part of the oxygen required in this process of decay is taken from the adjacent ferric oxide, which is thus reduced to the condition of pro-

toxide or ferrous oxide of iron. This is soluble in waters containing any carbonic acid, and thus may be carried off in solution as ferrous carbonate. Upon exposure to the oxygen of the atmosphere, however, or on evaporation, the iron gives up its carbonic acid and again forms ferric oxide. This latter process takes place in the red scum or film which forms on the surface of marshes or ponds filled with vegetable matter, and which occasionally breaks and settles to the bottom. In this way all the iron brought into the marsh in a state of solution may be precipitated in a bed at the bottom.

If there is an excess of decaying vegetable matter at the bottom of the marsh and the iron is still in such abundance that it cannot all be taken into solution it is accumulated in the form of ferrous carbonate, which is the ore so common in connection with the Coal Measures.

On this point Bischof says in his *Chemical and Physical Geology*, vol. 1, p. 170: "It is evident that the formation of this ore of iron must have taken place during all the earlier sedimentary periods since the appearance of vegetation upon the earth."

Carbonic acid is not the only acid produced by decaying vegetable substances which thus aids in the accumulation of iron ore deposits. Crenic acid, apocrenic and humic acids all give compounds of peroxides of iron which are easily rendered soluble with the aid of the ammonia produced by the same decomposition of vegetable matter. These acids undoubtedly play a larger part in the accumulation of bog ores than they have usually been credited with.

A quotation from Dr. J. S. Newberry may make this process clearer. After explaining how the iron is brought into solution by the aid of carbonic acid he continues: "Having now got the insoluble peroxide of iron into a soluble form, let us follow it in its travels. All the drainage of a forest-covered country may be asserted to contain iron. Where the rocks and soils hold this metal in unusual quantities the amount dissolved and transported is proportionately great, and many of the springs are chalybeate. Wherever these solutions of the salts of iron are exposed to the air they absorb oxygen, and the iron is converted into the hydrated sesqui-oxide. This we see in the precipitate of iron springs as yellow ochre; in bogs and pools it forms an iridescent film, which, when broken, sinks to the bottom of the water. If it there finds decaying organic matter, it is robbed of a portion of its oxygen, which unites with the carbon to form carbonic acid, and this bubbling to the surface escapes. The iron thus becoming again a

soluble proto-salt, and floating off, absorbs more oxygen, and carries this also to the organic matter, continuing to do this until all is oxidized; then it is precipitated as limonite or bog iron ore. Thus it will be seen that, under such circumstances iron plays the same part that it does in the circulation of the blood, where it is oxidized in the lungs and carbonized in the capillaries, serving simply as a carrier of oxygen."

Prof. J. A. Phillips in his "Treatise on Ore Deposits" p. 26, says: "There can be but little doubt that the majority of these stratified deposits of crystalline iron ores were originally thrown down in a hydrated form from aqueous solutions; but having been subsequently exposed to metamorphic influences, they have not only lost their combined water, but, like the rocks enclosing them, have become crystalline. It is probable that in some instances, they may have been deposited as carbonate of iron, which first lost its carbonic acid and subsequently became more highly oxidized."

One other method of the formation of deposits of bog iron ore was explained by Ehrenberg, a German microscopist, in 1836. He suggested that they are produced by minute infusoria whose cells consist mainly of hydrated oxide of iron. Of these the *Gaillonella** *ferruginea* is a notable example. It secretes iron oxide from dilute solutions and being found in many marshes and peat bogs it may play quite an important part in the accumulation of bog ores.

Lake ores are probably formed in a manner analogous to the bog ores. They are found in the Scandinavian lakes, and furnish considerable ore for the manufacture of cast iron. The deposits are found in the lakes at a distance of about thirty-five feet from the shore, and form a stratum averaging about a foot in thickness. Such a stratum when once removed is renewed in twenty or thirty years. The ore contains but a small per cent of iron, and is mixed with various impurities such as oxide of manganese, silica, alumina, lime, sulphuric and phosphoric acids. The structure of the ore is generally oölitic. Hausmann suggested that the iron in most of these deposits originated from decomposed iron pyrites in greenstones, and that many lake ores have been formed by the erosion and redeposition of neighboring bog ore deposits.

CRYSTALLINE IRON ORES.

A casual perusal of the accompanying bibliography will show the great variety of opinions held by different writers as to the origin of these ores. We shall glance at the various theories that have been proposed, and perhaps present some of the objections urged to them by others.

* This word is sometimes written *Gaillonella*.

Classification of Theories. Prof. A. A. Julien in the Proceedings of the Academy of Natural Sciences of Philadelphia for 1882, has given a synopsis of the various views on the origin of crystalline iron ores. He divides them first into "two classes, as they may refer the iron ores, enclosed in the subterranean strata, to an extraneous or to an indigenous origin."

A. THEORIES OF EXTRANEOUS ORIGIN.

1. Meteoric Fall.
2. Eruption as dykes, (or in masses accompanying basaltic flows.)*
3. Sublimation into fissures (or porous rocks.)

B. THEORIES OF INDIGENOUS ORIGIN.

4. Concentration from ferriferous rocks or lean ores, by the solution and removal of the (other) predominant constituents.
5. Saturation of porous strata by infiltrating solutions of iron oxide.
6. Infiltration into subterranean chambers and channels.
7. Decomposition of pyrite and other ferruginous minerals, enclosed in decaying schists, and transfer of the iron oxide in solution as ferrous sulphate.
8. Derivation from original deep sea deposits of hydrous ferric oxide, or of ferrous carbonate (deposited either by chemical precipitation or by mechanical sedimentation.)*
9. Deposit from springs.
10. Alteration of diffused ferric oxide into ferrous carbonate.
11. Metamorphism of ancient bog ores.
12. Metamorphism of ancient lake-deposits.
13. Violent abrasion and transport.
14. Concentration and metamorphism of iron sands.

To these fourteen divisions of Julien's may be added four more, namely:

15. True veins, formed by segregation or chemical secretion.
16. Electro-telluric action, *i. e.*, as a result of the reactions and decompositions produced by electro-magnetic currents in the earth.
17. Substitution of ferrous oxide for lime in the original rock, and change to peroxide.
18. Secondary product from the decomposition of basic rocks, eruptive or metamorphic; and concentration of the oxide of iron in drainage basins.

In the accompanying bibliography will be found quite full quotations from Prof. Julien's paper. We shall make frequent refer-

*For completeness we have added the portions in parenthesis.



SECTION OF THE KIOWA (PALLASITE) METEORITE, ORIGINAL MASS WEIGHED 211 POUNDS.
(American Geologist, vol. viii, p. 370.)

ences to it here and use it as the basis of our remarks, as it is the most complete and concise in its classification and discussion of the various theories of the genesis of crystalline iron ores. At the close of the chapter will be found a table which shows the supporters of the various theories and the dates of their advocacy of them.

Discussion of Theories. Our first theory is that of *Meteoric Fall*. This theory of the origin of a deposit of iron ore was advanced by C. J. B. Karsten in 1853. He supposed that the deposit of iron ore near Thorn in central Europe might have fallen from the sky, and described it as having a half melted appearance unlike that of most deposits of iron ore. There were at least 1,000 tons of iron in this deposit which covered about 700 acres of ground within four inches of the surface. The magnetic iron ore was intimately mixed with an olivine mineral and in this respect resembled some of the Minnesota ores.

Prof. Julien mentions the iron mountain of Cerro de Mercado, in Mexico as another which was described as of cosmic origin, and says that "such a view is sufficiently controverted by the mineralogical constitution of the mass, and its structure—'immense veins of specular iron ore standing nearly vertical.'"

In this connection may be noticed one or two of the observed occurrences of metallic iron in various portions of the world. In the *Annual of Scientific Discovery* for 1856 it is said that the Rev. Mr. Adamson reported meteoric iron to be abundant in South Africa; Pallas was said to have found it in Siberia in 1776, and others in South America, New Mexico and other regions.

In most text books on mineralogy and geology it is stated that native iron is only a curiosity and is not found except in meteoric masses. A section of such a mass of meteoric iron is shown on plate XL.

In 1870 A. E. Nordenskiöld discovered some large masses of native iron mixed more or less with olivine and other basaltic constituents on the island of Disco off the coast of Greenland. Native iron had been reported to exist there, and implements of wrought iron had been obtained from the natives, but the source of the iron they refused to disclose up to the time of Nordenskiöld's visit.

These masses of iron were several tons in weight, and as they contained nickel and displayed Widmanstätten figures Nordenskiöld believed them to be of meteoric origin; and finding them to be bedded in the basalt he came to the conclusion that an immense meteorite fell into the basalt when it was still molten and flowing.

Prof. G. Tschermak also advocated the celestial origin of this iron; but it has now come to be generally considered to be of terrestrial origin, as we shall see later.

2. *Eruption as dykes, or accompanying basaltic flows.* This view, as we have seen, was first proposed in detail by Hutton in 1795, and has had more numerous supporters than any other theory, but they were chiefly geologists of the first half of the century who advocated also the eruptive origin of quartz veins, limestone beds and even beds of quartzite, or who limited the igneous ores to certain magnetites and to native metallic iron, associated with basic eruptive or metamorphic rocks. The geologists who have during the last thirty years, persistently maintained the eruptive origin of those iron ores which are intimately associated with highly acidic, or siliceous rocks, are very few indeed.

The idea held by the supporters of this theory is that there is a large body of iron situated at a great depth from the surface, and that on account of pressure and the resulting disturbances, cracks have been produced in the crust of the earth, which fissures or cracks have been filled and overflowed by the molten iron from below, either as metallic iron or magnetic oxide of iron mixed with basalt.

W. W. Mather, in 1839, speaks of "injected veins" of iron ore penetrating the gneiss and crystalline schists of New York. These veins he considers to have melted the gneiss in some instances, but still to have maintained an abrupt contact with it instead of flowing together. He also thinks that the veins lead downward and are connected with the main mass below.

Sir R. Murchison satisfied himself that certain magnetites in the Ural mountains were not metamorphosed portions of sedimentary strata, but that they had flowed out of the adjacent hillside into the depressions they now occupy.

Foster and Whitney have frequently been quoted as the authors and advocates of this theory. In 1851 they advanced the idea that the iron ore deposits of lake Superior had been erupted in the bed of the ocean partly or wholly in the metallic state, and were subsequently rearranged by oceanic action and covered by succeeding sediments.

Dr. Ebenezer Emmons was an ardent advocate of the igneous origin of iron ores, as well as of quartz and calcite veins and beds of limestone.

Mr. H. D. Rogers recognized other modes of origin for some iron ores, but said in 1858 that "magnetic iron ore occurs only in the form of true veins of injection or genuine mineral lodes." Some-

times the ore has been "injected" into gneiss and again into sandstone.

B. Von Cotta, in 1864, accepted the eruptive hypothesis for many deposits of iron ore, magnetite, hematite, and even the carbonate of iron.

The magnetic ore of iron is the one most generally considered to be eruptive, as it is found in conjunction with basic eruptive rocks and in volcanic flows. It is quite an anomaly for any recent writer to express the opinion that various ores, both magnetite and hematite, where they are found associated so intimately with carbonate of lime and with quartz as to be inseparable from these minerals, genetically, are of igneous origin.

This anomaly is presented to us in two instances. In his *Acadian Geology*, 1878, J. W. Dawson describes a vein of iron ore associated with carbonates of lime and magnesia which he tells us is a good example of a vein filled by molten, or even sublimed carbonates of lime, magnesia and iron. This vein, he says, was subsequently partially roasted by heat "so as to produce the red ores, which are obviously the result of the heating and oxidation of a part of the carbonate of iron, and this process may be seen, on minutely examining the vein, to have extended itself from the walls of the smallest fissures."

This is a good illustration of the disregard of chemistry on which are based some of the early theories of the origin of iron ore deposits. To take notice of all the impossible and illogical arguments would be a tedious and useless task. The mere mention of them is sometimes enough to excite laughter. To say nothing of the impossibility of retaining the carbonic acid in the carbonates when they were subjected to such great heat as to melt and even sublime,* one cannot help wondering why subsequent

*On the volatilization of metals and metalliferous minerals and their redeposition in mineral lodes Pres. T. C. Chamberlin has written the following (*Geol. Wis.* 1873-79, vol. iv. p. 523); "The volatilization of the whole group of minerals presents great difficulties. The galena, to which attention is too apt to be confined, may be vaporized, without decomposition—at least can be volatilized and recondensed as galena—and the same may seemingly be accomplished in the case of pyrite and blende, but not of calcite. It is a familiar fact that, at a very moderate temperature, calcite (limestone) decomposes to caustic quicklime and that, then, not even the oxy-hydrogen blow-pipe is able to fuse, much less volatilize, in appreciable quantity, and to this property it owes its utility in the calcium light. To suppose that calcite is a product of sublimation is to severely tax credulity without the sanction of the slightest evidence. To the uninstructed objection that calcite is not an ore, it may manifestly be replied that it is as truly a metallic carbonate as smithsonite, and that it is only this immeasurable resistance to the decomposing effects of heat, that prevents its more frequent reduction to the metallic state, and possible use as a metal for certain purposes.

The relations of the ores in the lode are such as to require their deposition at the same time, in many cases, and they must, therefore, have been supplied simultaneously and maintained in coëxistence, till deposited.

roasting would oxidize the carbonates, and particularly the iron, if the original melting failed to do so; and we are further surprised to learn that the subterranean heating of spathic iron (ferrous carbonate) produces red hematite (ferric oxide). Here is a remarkable instance of oxidation in the presence of reducing agents. Other inconsistencies of chemistry and physical structure will be noticed in the description of this "vein," which is quoted in the appended bibliography..

A still more remarkable instance of this kind of geological indifference to chemical laws and reactions is found in the arguments of Dr. M. E. Wadsworth to prove the eruptive origin of the iron ores and jaspers of the lake Superior region. These arguments have been made very strong and have carried considerable weight as well from the high authority from which they emanated as for the ingenuity and assiduity with which he maintained his position, and the difficulty of advancing any other satisfactory theory owing to the complexity of the phenomena presented in this region. But, however plausible Dr. Wadsworth's arguments may be on general grounds, and however difficult it may be to explain all the observed facts in any other way, we believe that the simple fact that granular quartz occurs in a state of almost chemical purity inseparably mingled with the oxide of iron in a similar state of purity is sufficient in itself to overthrow the idea that they were erupted together in a molten condition. †

For the sake of those who are not familiar with Dr. Wadsworth's theory we will give the main points of his argument and mention some objections to them.

This is a very hard thing to believe, since there are such wide differences between their temperatures of vaporization and condensation.

It is easy enough to form a vague, general conception of the vaporization of metallic substances by the mysterious power of the unknown interior of the earth, but to form a precise, detailed view of just how galena, blende, pyrite and calcite, or the elements from which they were formed, volatilized simultaneously in the face of the fact that their temperatures of volatilization are immensely separated, presents Herculean difficulties, but these are dwarfed to Lilliputian dimensions in comparison with those encountered in attempting to imagine precisely how these several substances could have been condensed so as to form, within the space of a hand specimen, a group of regular, large-faced crystals that grew up together. A temperature that would admit of the deposition of one would be quite incompatible with the formation of another.'

†In "Lesley's Iron Manufacturers' Guide" are a few quotations (p. 364) from Bischof bearing on this point. From the example of iron welders who sprinkle sand on the end of the iron in order to convert the coating of magnetic oxide into silicate which peels off at every blow he says: "See then from these examples how impossible it would be to find quartz and magnetic iron separate if they were of igneous origin." And again after mentioning the quartz crystals in magnetic ore in various mines, he says: "Should the ultra-plutonists grant that the accompanying quartz is of watery origin * * * but still claim an igneous origin for the magnetic iron, they will find no escape this way, for the welding trick must be repeated on a grander scale in a supposed molten ore vein enveloping quartz, forming a silicate slag."

Dr. Wadsworth's views may be stated as follows: The jasper, which he has named jaspilyte, is acknowledged on every hand to be an inseparable part of the iron ore. The origin of one gives the origin of the other. They grade into each other and their interdependence is such that the relations of one to the country rock give the relations of the other.

The jasper and ore sometimes form what appear to be "dikes" which jut out from the main mass across the strike of the schists which constitute the country rock.

The schists are frequently hardened and discolored, or, as Dr. Wadsworth says, "baked" at the contact with these so-called "dikes" of jasper and ore.

The deposits of ore and jasper are lenticular, and masses of schist enclosed between various branches of the deposit are wedge-shaped, as if the ore was erupted from below, and surrounded the schist thus.

The banding of the ore and jasper is compared to the striped fluidal structure of rhyolytes and felsytes.

Some of the iron ore in Michigan being found to be in octahedrons, Dr. Wadsworth thinks is an indication that it was all magnetite originally and has been since changed to hematite by oxidation.

Crystals of hematite crystallizing from the molten magma of trachytes and rhyolytes have long been known, and are described in all the standard works on micro-lithology.

The jaspilyte and iron ore are sometimes cut up by cross-joints which give an apparent basaltic structure to the whole, making it resemble a dyke.

The uniformly fine grains of quartz which constitute the jaspilyte masses have been supposed to be the result of incipient disintegration of these very old deposits which are supposed to have been originally in the state of vitreous and glassy flows of acidic material. And the fact that the grains are unlike mechanically worn and chemically deposited quartz grains lends some strength to this position.

The above are the main points of Dr. Wadsworth's argument, and are mainly an elaboration of the views of Prof. J. D. Whitney, published in 1851. It is not strange that a pupil and a subsequent co-worker should have imbibed the same opinions held by Prof. Whitney for so many years.

But there are a great many objections to their theory,—objections which appear to us sufficient to convince any one, who thoroughly examines them and appreciates their force and application to the subject, of their validity and truth. A number of these

were given in the Fifteenth Annual Report of the Geological Survey of Minnesota, (1886) and will be repeated here.

1st. The inter-banding of the jaspilyte (hematite, jasper of various colors, white silica) is exactly that which is seen in sedimentary rocks. The different bands fade into each other across the structure by faint transitional stages. They maintain over long distances a parallel striping such as sedimentary thin laminæ do in all fine-grained rocks and clays, but when followed far enough they are seen to taper to points and disappear as their neighbors increase. In its hardened and apparently carbonaceous state this rock appears rigidly slaty, though still mainly siliceous, and stands on edge much like an argillyte. This slatiness is visible in some places where the tortuosity incident to folding and crushing has not been developed. It is straight and distinct, and is in consequence of the weathering out of some of the softer thin laminæ. It is found north of Tower, near the town, forming some of the conspicuous knobs facing toward the south. These slates are not black, but they are dark colored and remind the observer of some of the black slates of the Animike rocks farther east, and were it not for their perpendicular position, and their other relations to the surrounding rock-masses they could be considered their equivalent. This slaty structure is due to a weathered condition of differently constituted bedded materials, and differs from the slaty structure that may be developed in igneous rocks due to their fluidal structure, in that it is straight and rigid instead of undulatory or wavy. Rock No. 893.

2d. The jaspilyte, though frequently, and perhaps most frequently, presenting a sudden and definite transition to the schists, showing a possible igneous origin of one or the other, does not always do so. It is found passing by a series of short alternations into a schist, which, though greenish and easily confounded with the unconformable green schist, is a constituent part of the jaspilyte, or at least of the formation in which the jaspilyte exists. This structure and transition is represented by rock 894. It is here accompanied by much pyrite. This is obtained near the Ely mine, where the railroad cuts the formation. In this schist, thus alternating with jaspilyte, there is no sign of the "baking," so called, that is assigned to the red-colored schist at the mines, and the inference is natural and inevitable that the jaspilyte, here seen to be the contact rock on the schist, did not produce the effect of igneous dikes, and that this is the original condition of the mutual co-relations of these rocks.

This interbedding of schist and quartzite, the latter being somewhat purple, extends along the railroad as far east at least as to the Stone mine, where it is again well exposed (rock 919). Here the jaspilite passes by gradations into the green schist. In the immediate vicinity are jasper nodules indigenous in the midst of the schist, red and purple, some of them five or ten feet long, appearing like quartzose aggregations in the midst of their native sediments. Toward the south, at some little distance from the point at which this interbedding is visible, the siliceous grains are white, instead of purple, disposed in thin sheets.

At the West Ely mine the open pit shows, on the east wall, a succession of jaspilite and schist in beds somewhat like those sketched in figure 1, page 48.

Here we notice "wedge-shaped" masses of jaspilite surrounded by schist, which is just the converse of the cases reported by Dr. Wadsworth, and which indicated the eruptive origin of the ore. Here the same wedge-shaped masses would indicate that the schist is eruptive around and through the jaspilite. But the schist, besides grading off into graywacke and slate with an evident sedimentary banding, is found to contain rounded pebbles of vitreous quartz which prove its aqueous deposition—subsequent to its eruption. So that part of the evidence goes for naught.

At the East Ely mine, next adjoining on the east, the same bedded alternation of schist and jaspilite is apparent, but owing to the greater development it is brought out more distinctly. Figure 2 on page 48 of this bulletin represents the east face of this mine, the observer looking on the edges of the beds. Each one of these beds of jaspilite has a fine internal lamination which is much contorted. The schists, which are pervaded by a schistose structure when not reddened by iron, and which when reddened are less schistose, and "baked," though soft, do not manifest, so distinctly, a finer internal lamination. The four-inch bed of schist at the left of the sketch runs the whole length of the mine, and even appears on the stripped surface of the opened pit, running 500 or 600 feet altogether.

At the Stuntz mine the same regular (or irregular) alternation of beds of ore with red shale can be seen, there being visible three schist beds, from six to ten feet thick, dipping N. or N. N. W., about 80°.

In the foregoing tables of diamond drill borings on pages 27-36, the continual alternation of schist, jaspilite and ore is a very plain and persistent feature, and is in itself strong proof that neither the jaspilite nor the schist could have been erupted in

its present position, for in order that this regular alternation should be so uniform and general and should extend thus for miles, requires some cause which could open the crust of the earth in perpendicular sheets and inject equally thin alternating sheets of igneous matter. It is much more like the alternation of sedimentation, followed by upheaval and pressure.

3d. The schists are not by any means usually *baked* alongside of these jaspilyte belts and masses. This is shown by rock sample No. 894, and also by many other illustrations from other points that could be adduced. Rock No. 895 shows a gradual transition between the schists and the jaspilyte, without pyrite, near the same place as No. 894, not from between two jasper belts, but more distant, rather from the general mass of the schist. The contact is most commonly a simple one, with an abrupt transition, or there is a gradual interchange without any appearance of the so-called baking. This gradual transition is most apparent, and most frequent, in other places than along the great jasper belts.

The green schists themselves, at the same railroad cut, seem to become homogeneously arenaceous with the same (rounded?) granular quartz as seen in the jaspilyte—which, if true, (and subsequent observation in this and other localities has proven it absolutely) seems to require some other explanation besides the theory of incipient disintegration to explain the granular condition of the quartz in the jaspilyte. The theory that the rounded grains were thrown down as a sediment would then be extended rightly over both kinds of rock.

4th. In the enclosing green schists there are what appear to be not only pebbles, but lenticular masses of jaspilyte, or at least of jaspersy and chalcedonic quartzite. These are granular like all the rest, and easily distinguishable from the secondary or chemically deposited silica. Some are as fine as a pin-head, and do not show much, if any, disturbing effect on the fine laminae of the schistose structure, and others are somewhat larger, and larger, and larger, and produce some warping of the laminae, the warping extending further and further from their surfaces as their size increases. These minute pieces of jaspilyte are of the same character as the larger masses, and must have had the same origin. But they are so numerous that thousands may be embraced in the area of a square foot. They are sometimes distributed amongst the schist rather uniformly, and sometimes they are crowded about some of the larger masses. There is also a coarse breccia, with small and large, rounded and angular pieces of the jaspilyte, all embraced in a sparse matrix of green schist, resembling somewhat

a conglomerate. The inference is natural, and inevitable, that these jaspilyte pieces could not have been introduced as eruptive matter in the green schists, but must have been coincident in time with the advent of the schist. Their original, first formation and their source, would still be a matter of further investigation. (Nos. 889, 897.) Compare figures 3, 4 and 5, and plate III of this bulletin.

5th. The hematite can be seen in some places, where favorable circumstances have conspired to preserve the structural relations, to acquire the finely bedded or laminated or banded structure seen in the coarser bands of the jaspilyte. This is particularly visible where the hematite is specular — indeed the specular structure is due to the cleavage off of large surfaces of the ore along these lamination planes. In other places this fine striping is seen to fade out both longitudinally and transversely into a massive, hard hematite. This does not show, perhaps, that this banding is not a fluidal structure due to the eruptive nature of the rock, but it shows exactly the structure that would be expected in the rock if it were all of sedimentary origin—at least the jaspilyte—and it seems to indicate that the iron-ingredient is of the same origin and date as the siliceous ingredient and not of later date. It partially obliterates the characteristic fine lamination of the jaspilyte.*

6th. There are places, not common, where the iron ore seems to be a breccia of jaspilyte and "baked clay," or, more likely, a highly ferruginated and hardened clay. Generally they are better ores when associated with the large jaspilyte belts, and poor when in small particles. These breccias are supposed to form a constituent part of the iron-bearing strata, and should not be confounded with those conglomerates made up by the mingling of transported masses of jaspilyte in the enclosing green schists. This ferruginization of fragments of both jasper and clay, in a breccia, seems to show that the iron, as an ore, is not necessarily a part of the jaspilyte, and this idea is strengthened by the fact that the ore of the Gogebic range is one that consists largely of a breccia of some soft rock. If then the hematite be not essential to the rock known as jaspilyte, the residue would be almost entirely silica, and it is a novelty to suppose that pure silica could ever have been injected among the rocks of the earth in the form of igneous dikes. If, on the other hand, we believe, as we do now, that the iron and silica

* It is probably because the iron ore has been subjected to pressure and heat that the lamination is obscured or erased, and not because of any difference in date or manner of origin. When it does not totally obliterate it, it accommodates itself to that structure. Rock 905.

were deposited together, and the hematite does constitute an essential part of the jaspilyte, the novelty of supposing it injected is three-fold what it was before: 1. The injection of molten silica; 2. The injection of molten hematite; 3. Their uncombined state chemically, and the distinctness with which each stratum or ribbon preserves its outlines without having flowed together with those on either side.

7th. When this silica, which has been styled chalcedonic, interleaved with the hematite and jasper, is weathered, and finally disintegrates, it crumbles into a fine white sand, the grains being of uniform size. It is then friable like the St. Peter sandstone, and could be used for scouring and polishing. If a large piece of such weathered "chalcedonic" silica, carefully selected, be thrown down on the face of the firm jaspilyte, it is crushed with a dull explosive noise, the individual grains of silica flying from the point of impact in all directions, the phenomena being the same as when a slab of soft sandrock is thus thrown down on a hard surface. On the contrary, when a piece of the chemically deposited silica, taken from some of the veins with which the country rock is everywhere intersected, is thus treated, howmuchsoever it may be weathered, it is either splintered into sharply angular bits of various sizes, or is simply crushed into white powder on some of its corners. In this the white "chalcedonic" silica behaves like the quartzites at Pipestone and New Ulm. They are also sometimes vitrified superficially and very hard, with the appearance, including the color, of much of the fine quartzite seen in the jaspilyte but when disintegrated by the atmosphere they dissolve into a homogeneous white sand. Rocks 869, 899, 900.

8th. It is apparent at many places about the Vermilion mines that the great mass of the iron formation (the jaspilyte) is conformable with the schistose structure of the schists that inclose it. It is absolutely conformable with the schists that are, at some points, a little removed from the mines, interstratified with it; and, in a general way, it is conformable with the structure of all the surrounding schists. On the supposition that the jaspilyte be igneous these schists also would have to be considered sedimentary, and this schistosity would have to be taken for the sedimentary structure,* the unconformities, wherever they exist, being due to the fracture of the beds, and the introduction of the fluid jaspilytes. Now in order that such a conformability should exist *at the time of the accumulation of the sediments* on any hypothesis, the jaspilyte

* Dr. Wadsworth seems to have so considered it in his paper on the Marquette ores; without, however, vouching for its correctness.

must have been introduced at the time of such accumulation and while the sediments were yet soft; and that, on the igneous theory, would not account for the angles and arms and "dikes" that Dr. Wadsworth has illustrated at Marquette, running across the sedimentary structure of the schists; and would require that there should be, besides, a marked difference even now, in the upper and lower surfaces of such inflowing igneous strata, such as we do not see.

9th. If the jaspilite be supposed to have made its advent after the sediments were hardened there is no other way but to resort to the igneous theory, and then we have many difficulties, viz.:

(a) Why should it appear always at the same, or nearly the same, geological horizon? No other admittedly eruptive rock does that.

(b) Why should it run substantially conformable to the stratification in all the important localities? No other admittedly eruptive rock does that.

(c.) Why should the bulk of the whole be a granular silica? There is no other such igneous rock known. If it be said that the granular condition of the silica be due to incipient disintegration, why does the same granular condition prevail at the depth of seventy-five or more feet (nay, 875 as found in diamond-drill cores) below the surface, as found in the Vermilion mines?

(d.) How could the oxides of iron coexist with silica at the temperature needed for fusion without chemical union? No other instance is known.

(e.) How could the evenly banded, long-drawn out, almost never-blending layers seen in the jaspilite, consisting of the same elements in endless alternation (hematite, jasper, quartzite,) be imagined to have been preserved in their tortuous parallelism during such a flow through open fissures? No other such fluidal structure is known. The real igneous fluidal structure shows a *general parallelism* in the structural lines, in a nearly homogeneous rock mass, but the fine bands separate, cross over, blend and mingle in a general flow, at longer or shorter intervals.

(f.) How does it happen that the so-called flowage structure is not parallel with the surfaces of the rock walls, in cases where the jaspilite enters arms or bands or jogs off in the fissured schists? In no case, in the Vermilion mines, has such a parallelism been seen yet; but, either the structure is entirely lost, or it is confused by many fractures, or runs at various angles, even to perpendicularity, to the walls of such a fissure (as at the Stone mine). In other admittedly eruptive rocks the fluidal structure is parallel

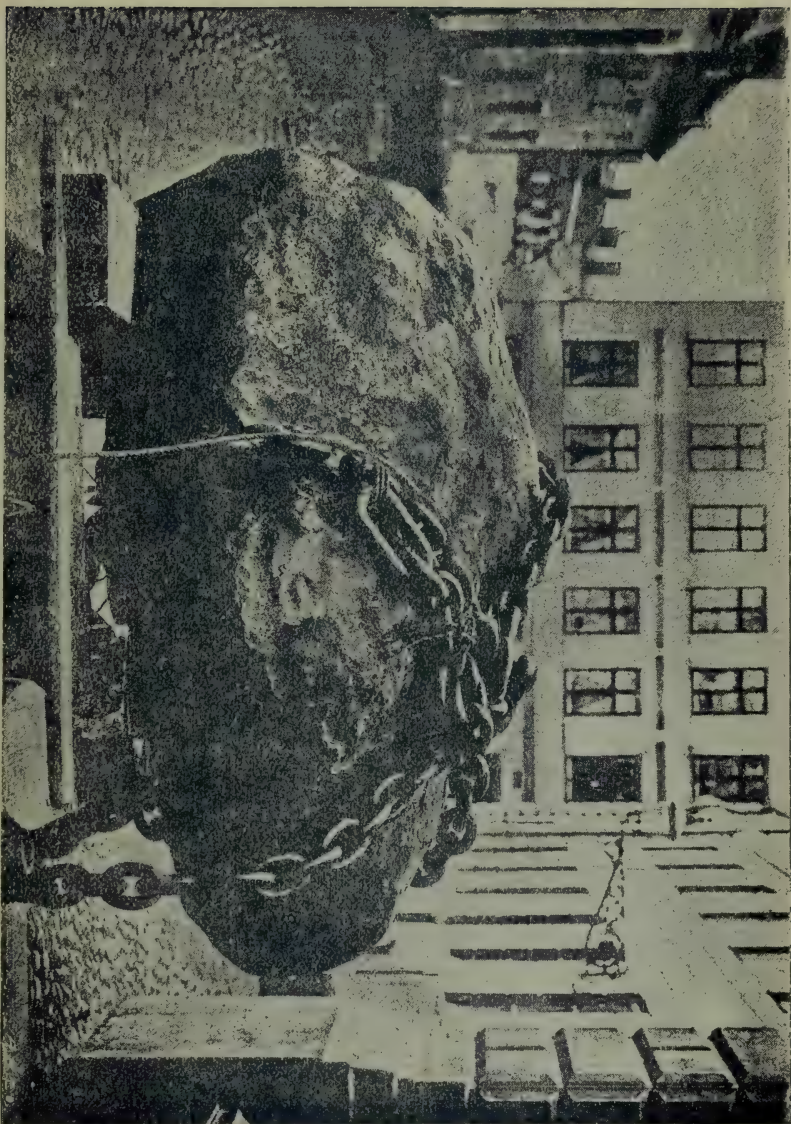
to the walls of the enclosing rock—at least is parallel to the direction of the flow.

The above are the reasons for advocating some other than an eruptive origin of the jaspilyte, based mainly on the observations of the season of 1886, and substantially as given in the fifteenth report. Since then three summers' observations have served to show the general correctness of those views and to produce further arguments against the igneous origin of the jasper and iron ore. These further facts will be found in the seventeenth and eighteenth annual reports, and are summarized in another chapter of this bulletin, combined with some microscopic investigations.

One significant fact is the presence of rounded grains of vitreous quartz occasionally found in the jasper. These are plainly water-worn pebbles of earlier date than the silica of the jaspilyte. If the jaspilyte were eruptive, and its present granular nature be due to incipient disintegration, the question arises, why have not the still older pebbles contained in it succumbed to the same influences and become finely granular instead of remaining perfectly round and vitreous?

But while it is evident that iron oxides could not have been erupted in company with the most acidic kind of material (quartz) and not form chemical combinations with it which would destroy their character and value as iron ores, there may be conditions in which extensive deposits of iron, either as an oxide or in a metallic state, have come in a fused condition from the depths of the earth. In 1852 Prof. T. Andrews, in a paper before the British Association for the Advancement of Science; "succeeded in showing that native iron is by no means an uncommon constituent of basaltic rocks." He found it most abundantly in "a coarse-grained variety of basalt, which forms the hill of Slieve Mish in Antrim." Native iron not meteoric was reported to have been found at various places both before and since this account of Prof. Andrews; but no general credit was given to these reports until Nordenskiöld's discoveries in Greenland.* The latter masses of iron were very thoroughly analyzed and discussed in Europe, and their terrestrial origin has been finally accepted by such men as Walter Flight, A. Daubrée, K. J. T. Steenstrup, J. L. Smith, M. E. Wadsworth, J. W. Judd and H. Hensoldt. One of these masses of iron is seen on plate XL. The most of these writers believe that the masses came to the surface in the form of metallic iron. But Steenstrup and Smith think it was reduced to the metallic state by beds of lignite through which the eruption passed on its upward way.

*See also *Chancourtois* and *Rohde* in the Bibliography.



MASS OF METALLIC IRON FROM THE BASALT AT OVEFAK, DISCO, 1870. NOW IN THE ROYAL ACADEMY
AT STOCKHOLM, SWEDEN. GREATEST DIAMETER ABOUT SIX FEET. WEIGHT 19 TONS.
(Geol. Mag. Decade 11, Vol. ii, 1875.)

However that may be, it is an accepted fact that eruptions of magnetic iron ore have occurred in connection with *basic* rock (*i. e.*, with rocks containing less than 55 per cent. of silica); and another of the dogmas of the mineralogical text books will have to be discarded, viz: that metallic iron is not found except in meteorites.*

In the erupted gabbro of the Mesabi range in Minnesota there is a large amount of magnetic iron ore which occurs in disseminated grains and in large massive deposits. This ore is not exploited at present owing to the lack of demand for ores containing titanium, which element sometimes constitutes fifteen or twenty per cent of the gabbro iron ore. There is no doubt in our minds that this ore is genetically inseparable from the gabbro, which is on all hands acknowledged to be a true eruptive rock. It also seems likely to us that the presence of titanium in iron ore is always a strong indication of its igneous origin.

3. *Sublimation into fissures or porous rocks.* This theory for the origin of ore deposits was first proposed by Lehmann in 1753. It is very closely connected with the foregoing and in many cases has grown out of it. Becher (1669) and Henkel (1725) both supposed ores to be deposited by vapors, but Lehmann was the first to give any clear idea of the real agents supposed to aid in the process. In the early part of this century small deposits of hematite and magnetite were noticed to have been sublimed from the hot vapors issuing from certain active volcanoes. Ever since then there have been advocates of the formation of large deposits of iron ore in fissures connected with reservoirs of molten matter in the interior of the earth. It has been supposed by several that these hot vapors penetrated porous beds of rock like sandstones and deposited the red coating of peroxide of iron which surrounds the individual grains. This appears to have been Dr. Emmons' idea, and not that the grains were coated with an infiltrating liquid solution as Prof. Julien says.

It is evident that this theory cannot be applied to deposits of ore in regions that do not show any signs of volcanic action, and the amount deposited from large volcanoes in a great space of time is so small that we can not look for any such immense deposits as we find in various parts of the earth.

Of the three theories of extraneous origin, therefore, we find: (1) That, while masses of iron ore do fall upon the earth, and while there is no known reason why such masses should not be large enough to be worked for their iron, yet no cases are at pres-

**Vid.* H. S. Osborne's "Minerals, Mines and Mining," 1884.

ent known of such an occurrence.* (2) That large quantities of iron ore are erupted together with basic rock material from a source deep within the earth and that these deposits may form valuable mines of iron ore if titanium does not interfere. (3) That no large amounts of iron ore have come from sublimation.

B. THEORIES OF INDIGENOUS ORIGIN.

4. *Concentration from ferriferous rocks or lean ores*, by the solution and removal of the other predominant constituents.

Although G. Bischof in 1847 showed that it was quite possible for iron ore deposits to be formed in this way and even went so far as to state that "any mineral may form an iron ore bed" by the process of decay and removal of all but the oxide of iron, it is mainly since 1865 that this method of the formation of limonites and certain other ores has been advocated. It is quite possible that certain non-crystalline ores of iron may have been formed in some such way. But it is rather more natural to suppose that the oxide of iron would be carried away either in solution or in minute solid particles by the same meteoric agents which removed the other constituents of the rocks. Moreover, this process is, as Prof. Julien says, a subaërial ore, and the ores which might be formed in such a way would have no genetic relation with crystalline iron ores enclosed in submarine sediments. Prof. Julien further remarks: "Even were the theory satisfactory in regard to the pure ores, the essential question remains unanswered, viz., the genesis of the original 'ferriferous or lean ores' themselves;" an objection which he apparently did not observe would apply to his own theory, *the concentration and metamorphism of iron sands*.

5. *Saturation of porous strata* by infiltrating solutions of iron oxide. This theory was very plainly indicated by L. Vanuxem (1838) in reference to certain ferruginous sandstones of New York. It was adopted by J. M. Safford in 1856 to partly account for some of the Tennessee ores, but he used it in connection with the next theory.

Dr. Adolph Schmidt believed that it would explain to some extent the origin of the Missouri iron ores, and J. P. Kimball applied it to some ores of Cuba.

It is quite evident that although certain porous rocks might become very strongly impregnated with iron oxide and even become lean ore, yet no ores could be formed by this means alone which would equal in purity the hematites and magnetites of the crystalline and older sedimentary rocks.

*No account is taken here of the probable early Mexican and African use of meteoric iron.

Prof. Julien quotes Dr. Emmons as an advocate of this view, but a perusal of his writings on the subject will show that it was not his idea that infiltrating waters carried the oxide of iron which covers the grains of sand in the ferruginous sandstone, but that vapors produced by molten rocks in the vicinity permeated the rock and deposited the iron in question. This is also more in accordance with his general notion of plutonic forces.

6. *Infiltration into subterranean chambers and channels.* This idea is very similar to the last, and may be admitted to account for recent limited and irregular deposits of limonite. But cavities a mile or two in length and from fifty to two hundred feet in width cannot very well have existed in rocks of such composition and structure as those which contain the crystalline iron ores. The physical structure of the latter is another proof that they were not formed by such a process.

This theory has been advocated at least since 1847 and probably much longer.

7. *Decomposition of pyrite and other ferruginous minerals, enclosed in decaying schists, and transfer of the iron oxide in solution as ferrous sulphate, to be precipitated as ferrous carbonate or ferric oxide.* Prof. C. U. Shepard appears to have been the first to advance this theory of the origin of any iron ores, and as early as 1837. He deserves great credit for his work, and his writings show him to have been far in advance of his time, in the originality and correctness of his ideas. He recognized the fact that the ore deposits of Connecticut which are embraced in the gneiss, are not veins, although they stand in vertical position, but are *beds*. He considered that the decomposition of the pyrite element of the schists might account for limonite deposits, but did not think the iron was carried away in solution and deposited elsewhere.

Ten years later Bischof showed how decomposing pyrite might produce iron ore deposits; but while we must give him credit for great insight into the chemistry of nature, and must concede priority to him in many things, in this case he was antedated by a pioneer American geologist. This theory has by implication been extended from limonite to the crystalline iron ores, though it is usually applied only to the former. "Its connection with the crystalline iron ores is rendered improbable by the absence of associated limestones (to precipitate the carbonate of iron from the sulphate solution), or, if present, by the lack of evidence of their erosion." This theory will certainly account for the existence of some limonite iron-ores, and to this the writers refer those limonites that have been mentioned in several of the Minnesota reports, lying between

the Cretaceous and the Paleozoic rocks that are unconformable beneath the Cretaceous (as in Blue Earth and Fillmore counties), and which also appear in isolated, generally small, pieces on the tops of the bluffs along the Mississippi river in Goodhue and Wabasha counties. This ore exists in workable quantity at several points in western Wisconsin, and recently has been employed in making iron at the furnace at Black River Falls. At numerous places it is in contact with the "Potsdam" sandstone in Wisconsin, and has been described and discussed at length by professors Strong and Chamberlin in volume IV of the report of the Wisconsin survey. There is no evidence, however, that the sulphide, on decomposition, lost the iron by solution and consequent removal. On the contrary the pyrite has plainly simply been oxidized and hydrated *in situ*.

8. *Derivation from original deep sea deposits of hydrous ferric oxide, or of ferrous carbonate deposited either by chemical precipitation or by mechanical sedimentation*, dehydrated by subsequent heat, as in the case of hematites, and deoxidized by hydrogen or by further heating, forming magnetites.

This is a very comprehensive theory and might be divided into several which are modifications or variations of it. Different writers have assigned different sets of circumstances to be the causes which induced oceanic deposition of ores. It is probable that there is some truth in all of them, and each particular deposit or class of deposits may have been formed in a manner differing slightly from all others. The conditions surrounding and governing the sediments held in suspension or solution by the ocean's waters must be carefully studied in each case before the exact nature of the deposits can be ascertained. This has not been done in many localities, and as a result the ideas held by advocates of different phases of this theory are often vague and lacking in completeness.

Dr. Edward Hitchcock appears to be the first who advanced this view of the genesis of iron ores, in 1833. In 1861 he repeated and elaborated his earlier conclusions. Too much credit cannot be given to this pioneer in the geological field for his careful statements and clear insight into the origin of rocks and minerals, and the nature of the subsequent changes which have affected them.

C. U. Shepard, in 1837, and J. W. Foster, in 1849, found physical marks upon certain beds of iron ore, which indicated that they had a community of origin with the strata which enclose them, but they did not explain in what condition the iron was deposited.

J. D. Whitney in 1855 presented some very thoughtful considerations upon iron ore deposits; and he described very truly the sev-

eral ways in which iron ore bodies may be produced. But his theories were much better than his application of them to particular cases. He advocated eruptive masses of metallic iron and of magnetic iron ore, and we have seen that there are well established examples of both; but very anomalously, he considered the lake Superior hematite ores, which are exploited at present, eruptive, and there are very many reasons why they cannot be. He says of the Pilot Knob iron ores, that "These deposits seem to have been of sedimentary origin, having been originally strata of siliceous sand which has since been metamorphosed. The iron ore may have been introduced either by the sublimation of metalliferous vapors from below during the deposition of the siliceous particles, or *by a precipitation from a ferriferous solution, in which the stratified rocks were in process of formation.*" Prof. Whitney came very near announcing an important general truth, and if he had himself dwelt more upon the idea which we have put into italics we feel sure he would have perceived its applicability to the siliceous hematite ores of the lake Superior basin, particularly as he so well understood the nature of the enclosing Azoic rocks.

Von Cotta also advanced views of the precipitation of iron ores which are quite similar to those of Whitney: "There can be no doubt that all true ore-beds were originally formed by mechanical or chemical precipitation from water."

In 1858 H. D. Rogers described a possible method of the formation of the fossiliferous iron ores of his "Surgent" series to be by the precipitation of peroxide of iron in the ocean. The calcareous and fossiliferous nature of those strata was to him an indication "that the epochs of the deposition of the iron ore were also the periods of the most copious supply of carbonate of lime," which would act as a precipitant of the peroxide of iron from solution.

These three statements are the only instances we have discovered in which the chemical precipitation of ferric oxide in the ocean has been assigned as a possible explanation of iron ore deposits—and here only theoretically or as an alternative view to some other rather to be preferred or supplementary to it.

J. P. Lesley advocated the chemical precipitation of carbonate of iron to form portions of subterranean strata, and stated that iron might be found "in any of its mineral combinations in the oldest rocks without having resort to the igneous theory." B. S. Lyman is another who thought that the iron ores found in sedimentary strata, particularly in limestones, were precipitated in the form of carbonate of iron. This method of formation of iron ores was applied by R. D. Irving to the ores of the lake Superior region. He

stated that he found traces of the original carbonate still left in the rocks in some places. Prof. C. R. Van Hise also in a very ingenious and interesting paper upon the "Iron ores of the Penokee-Gogebic series of Michigan and Wisconsin"* expresses the view that "the iron formation deposits were originally an impure cherty carbonate of iron." The mistake made by Profs. Irving and Van Hise is the same that has been made for hundreds of years, viz., too wide an application of a theory deduced from limited observations. Because it was found satisfactory for one set of facts and for one class of ores they considered it valid for a somewhat different set of facts and for ores that belong to a far older formation. Prof. Van Hise, however, says he only suggested that the ores of the Tower region in Minnesota may have had a similar origin, though he and Irving both regard the Vermilion lake ores as of the same age as those to which they applied their theory in Wisconsin.

It is not quite clear whether Prof. Irving regarded the carbonate of iron as precipitated in oceanic water without the action of decaying organic matter, or in surface waters in the same way that bog ores are now formed. He says: "These ferruginous rocks were once carbonates analogous to those of the Coal Measures." We are led to infer that he supposed the precipitation to have taken place in the presence of abundance of decaying organic matter. It appears, further, that iron carbonate is precipitated in presence of super-abundance of organic decay, but until then the precipitate is ferric oxide. (Compare J. S. Newberry, Proc. Lyc. Nat. Hist. of New York, Vol. 1, 1870-71, pp. 36, 37; Monograph XIV, U. S. Geol. Survey, pp. 7-8; Newton, Geology and Resources of the Black Hills, p. 138; I. C. Russell, Bull. 52, U. S. Geol. Survey, p. 45, 1889.)

Dr. M. E. Wadsworth may also be quoted as an advocate of this theory, though of what particular phase of it is not clear. He has said, however, that he holds that the iron ores of lake Superior "are chiefly eruptive, partly intrusive, partly in overflows; also formed in part by decomposition of the jaspilyte and ore *in situ*, and in part by mechanical and chemical deposition."

Under this general head comes also the theory adopted in this report of the origin of the iron ores of the Keewatin. An outline of the process of formation which we believe is indicated by the nature of the rocks of that series and the relations it sustains to the ore lenses may be given here without mentioning all of the phenomena which have led us to adopt this theory.†

**Am. Jour. Sci.* (iii) xxvii: Jan. 1889, pp 32-48.

†For a further statement of the views of the writers see *Am. Geologist*, Vol. IV, No. 5, 1889, pp. 291-300; Vol. IV. No. 6, pp. 382-385.

We believe that the jaspilyte and ore lenses were formed at the same time that the enclosing rocks were deposited, and that they have undergone but very slight mineral or chemical modification since that time. There is in the rocks which surround and enclose the iron ore bodies indubitable evidence of the action of both volcanic and aqueous agencies in their formation and deposition. In order to understand the circumstances under which the oxides of iron and silicon, which compose these immense deposits, were formed we must consider that it was at a very early age in the history of the world; that the crust of the earth was thin, and contacts between molten material and the oceanic waters were frequent and the resultant disturbances violent; that the waters of the ocean were capable of dissolving a greater amount of silica and iron as well as of other ingredients than in modern times, because they were heated and liable to be charged with intensely solvent chemicals. The high temperature of the atmosphere and of the ocean's waters would prevent the precipitation of all the more volatile minerals, but oxides of iron and silicon would be formed and precipitated wherever evaporation or cooling of the oceanic waters took place. Currents would be formed in the ocean by the heat from fissures or proximity to volcanic vents as well as by the same causes which produce them in modern times. These currents would carry away warm saturated solutions heavy with their load of iron, silica and other substances into cooler portions of the sea, where precipitation would take place, and accumulations of mingled silicic hydrate and hydraous ferric oxide would be formed.

Other portions of the ocean's waters were heated and rendered capable of taking into solution still further amounts of iron and silica, two chief ingredients of the volcanic matter which was being continually or at intervals erupted and deposited in the bed of the ocean.

In this way can be understood the minute interbanding of dark ferruginous and lighter silicic bands in the jaspilyte, also the minutely fine granular structure of the silica, the occasional dissemination of this silica through the green schists and in fact nearly if not quite all of the varied phenomena observed in connection with the ore and jasper lenses of the Keewatin.

Subsequent pressure alone is sufficient to dehydrate the oxides, and aside from that we believe very slight changes have affected the general masses of the ore or the rocks of the whole formation. The occurrence of the ores and jaspilytes in lenticular masses is easily explained when we consider the action of the oceanic currents. It is what is always found in true subterranean deposits.

Prof. Julien says in this connection: "The strongly marked lenticular form and laminated structure of all deposits of crystalline iron ores—and even of the numerous smaller lenses, parallel or overlapping, which make up the large deposits—are unmistakably characteristic of marine accumulation, Neptune's own royal stamp."

The careful researches of Prof. R. D. Irving impressed him very strongly with the fact that the silica of the jaspilyte was chemically deposited from bodies of water. A few quotations from his article in the American Journal of Science in October, 1886, on the "Origin of the Ferruginous Schists and Iron Ores of the Lake Superior region" will suffice to show this. "The silica, which frequently forms so prominent a part of the ferruginous schists, and which is at times jaspery, but is far more frequently cherty or even chalcedonic—a point hitherto quite unrecognized in publications on this subject—presents every evidence, both in the thin section and in the field, of a chemical origin. In the thin section—in that it shows ordinarily no trace of a fragmental texture, even when relatively coarse-grained, and in that it approaches more commonly to the peculiar chalcedonic or even amorphous forms known to occur only with silica deposited directly from solutions; besides which it traverses and follows the banding indifferently and in such a manner as to place its secondary nature beyond all doubt. (?) * * * The facts above cited * * * prove incontestably the chemical origin of the silica. * * * We were thus restricted to some theory which should account for the precipitation of most of them essentially in their present conditions, with perhaps some slight internal rearrangement; or to one in which the production from some form of sedimentary deposit of the conditions obtaining, should be assigned to metasomatic processes, carried out, in part at least, at a very remote period. * * * While we have, perhaps, in the deposition from some modern siliceous springs, a slight analogy to the interstratification of iron sesquioxide and silica, this analogy is, after all, but slight * * * and there is nothing in the structure of these deposits to indicate spring deposition, *and everything to indicate deposition in bodies of water.* But of the formation of such deposits by chemical deposition in bodies of water we certainly have no modern instances. * * * Later, as further study developed the fact that the least altered forms of the ferruginous schists contain a considerable proportion of some carbonate—the amount of carbonate increasing inversely with the amount of disturbance and alteration—the idea of a possible formation of these rocks by chemical deposition approximately in their present conditions gave place to

views which included the idea of a replacement of some rock, originally dolomitic or calcitic, by siliceous and ferruginous substances."

It thus appears that Irving was almost driven to accept the theory of chemical deposition of the ore and jasper in the ocean in substantially the same condition that they exhibit in the rocks at present. But, because there is no example in modern times of just such a deposit, and because he found carbonates in connection with some of the iron ores (Huronian) he abandoned conclusions at which he had correctly arrived, and which were valid for one set of rocks (Keewatin) in which he saw the other phenomena. Unfortunately he tried to make the phenomena and chemical conditions of one class of ores (Huronian) produce a theory to cover ores and phenomena that pertain to an older formation. He was continually misled by his inability to separate these two great geological formations, and to distinguish the differences in their respective ores.

It was suggested by W. A. Crosby that the ferruginous nodules in the deep-sea ooze might furnish a clue to explain the formation of the jaspery iron ores; but there is no clear relation between the continuous laminations and banding of the jaspilite and the scattered nodules of the ocean bottoms to-day, though with proper modifications this germinal idea may be applicable in a wide sense.

9. *Deposit from springs.* It has been observed that around the mouths of springs oxide of iron has been precipitated by oxidation from solutions of ferrous carbonate or by mechanical deposition of minute particles of ferric oxide brought out by the water. Bischof mentioned such deposits and suggested that they might aid in the formation of iron ore beds. But it is evident that if the world's supply of iron had to be derived from this source, we should never hear of an "Iron age."

10. *Alteration of diffused ferric oxide into ferrous carbonate.* The only geologist who has been found to advocate this method of the formation of iron ore deposits is W. B. Rogers. He supposed that carbonate of iron was produced by the reducing action of organic matter brought in contact with it *in situ* in the rocks and not in infiltrating waters. Forces of segregation afterward accumulated it in irregular strata. He accounted in this way for the iron ore of the Coal Measures.

His explanation has not been accepted by any one so far as we know, and could not apply to ores enclosed in rocks which were deposited before the presence of organic life on the earth.

11. *Metamorphism of ancient bog ores.* It was suggested by Robert Bakewell in his Introduction to Geology, 1833, that iron-stone may have been "the produce of decomposed vegetation as bog or peat-iron is supposed to have been." But he disclaims for himself and brother geologists any certain knowledge of the mode of its origin. Dr. W. Kitchell in 1856 "opposed the theory of the igneous or eruptive origin of the magnetic ores of New Jersey, maintaining that they 'were of sedimentary origin and had been deposited just as the gneiss and crystalline limestone had.'"*

Twelve years later Prof. Geo. H. Cook supported the views of Dr. Kitchell and remarked that "the magnetic iron ores of this state (New Jersey) have originated from chemical or mechanical deposits, just as our hematites and bog iron ores do now."

In 1869 T. S. Hunt championed this view and put forth many arguments to sustain it. His views on the subject have frequently been quoted and will be found in full extracts under his name and that of Julien in the appended Bibliography.

Since Hunt many prominent geologists have held this view, among them are J. D. Dana, J. S. Newberry, Jos. Le Conte and A. Geikie. With such an array of eminent authorities to support it it would seem as though it were inevitably sound and valid. But while it may be true and very likely is, that iron ores may be rendered crystalline and massive by metamorphism and that some deposits of magnetic ores associated with Palæozoic rocks have been changed from bog ores by contact with recent eruptions, it is quite certain that all crystalline iron ores cannot be explained in this way, and that the presence of iron ores in Archæan rocks is no more evidence of the existence of organic life at that age than the presence of quartz or any other oxide.

Some geologists have been so carried away by their desire to discover evidences of the existence of life upon the globe much earlier than there is any reason to believe it did exist, that they ignore other more possible and more probable methods of the formation of per-oxide of iron, and overlook features in the rocks themselves that are incompatible with the existence of life at the time they were being deposited.

The frequent occurrence of graphite in intermixture with the crystalline iron ores and in rocks of Archæan age has been cited by the advocates of this theory as proof positive or at least strongly indicative of plant and animal life at that early period. But on this point Prof. Julien says: The general absence of

*Julien *op. cit.* This theory is put by Julien in this category, though it might be classed under Theory No. 8.

graphite "seems to prove that it cannot be chiefly derived from the organic matter (1 to 36 per cent.) contained in all limonites, but rather, it may be, from the algæ and marine plants sometimes finding their growth and entombment in the iron-sands, even of iron oxide, in shallow water."

The discovery of graphite in meteorites, as remarked by J. Lawrence Smith, has an important bearing on this question and proves that it is not at all necessary to suppose that graphite is only to be derived from the remains of animals or plants. Dr. M. E. Wadsworth says:* "To make graphite the evidence of life is the same kind of argument as it is to claim that no oxides of iron and no carbonate of lime could be formed without the intervention of life. One we knew to be oftentimes of volcanic origin, and the other to be frequently the product of the decomposition of rocks."† In Whitney and Wadsworth's "Azoic System" (Bull. Mus. Comp. Zool, Vol. VII. 1884) the subject of graphite and its value as an indication of life is fully discussed, and the conclusion is reached that there is no proof whatever that graphite is the result of the decomposition of vegetable matter. They state: "That we know of no other way in which graphite can be artificially formed than indirectly in connection with, or as one of the results of, some process or operation carried on at a very high temperature." There is thus no reason why it may not have constituted a primary constituent of the earth.

The idea that iron ore is an indication of life is thus disposed of by the same writers: "In default of other evidence of the presence of the results of organized existence in the azoic rocks, it has been maintained by some that the occurrence of ores of iron in extraordinary quantity in that series furnished the desired proof. The facts are, however, that some at least of the iron thus occurring is of eruptive origin; that the oxide of iron is a mineral commonly and abundantly found making an essential component of volcanic rocks; that metallic iron is so found in large quantity,—in one region, at least; that there is strong reason for believing that metallic iron forms, if not the whole, at least a large part of the earth's interior; and finally, that a large portion of the material which comes to us from outside our planet is metallic iron. All this, we think, is amply sufficient for a refutation of the theory,

*Lithological Studies, p. 67.

†On this point Hunt says: (Am. Journ. Sci. (iii) ix, 1880, p. 353) "While some have imagined an inorganic origin to the carbon found in the form of graphite, and, even to petroleum and to coal, sound reasoning is, we think, on the side of those who, starting from the conception of an originally oxidized globe, see no evidence of any process of deoxidation therein which does not, directly or indirectly, depend upon vegetable life, and hence assign an organic origin to all carbons and hydro-carbons."

that the presence of the ores of iron is a proof of the existence of life at the time when the rocks were formed in which those ores occur."

In the face of such facts as are mentioned above the reiterated statement of Le Conte that "both *now* and *always* iron ore is and has been accumulated by organic agency" appears to be the result of an insufficient examination into the fundamental principles of chemical geology.

One reason why geologists have clung so tenaciously to the action of organic matter is because it has seemed necessary to have some way to reduce the iron from the sesqui-oxide to the protoxide condition, in order to get it into solution. This was wholly unnecessary labor on their part and only involved them in greater difficulties. The iron contained in the various basic rock-composing minerals of the silicate order is already in the protoxide or soluble condition, and ordinarily becomes oxidized or changed to the insoluble peroxide when the mineral disintegrates and its soluble ingredients are removed in solution by meteoric waters. But if the iron were dissolved before it had a chance to become insoluble there would be no reason why it could not be carried off and added to some other iron obtained in the same way and the whole deposited by evaporation and precipitation in the shape of a bed of ferric oxide.

During the Keewatin period especially would this action have taken place upon a large scale; the basic material thrown into the turbulent ocean would be largely dissolved by its alkaline waters, and the iron of the silicates or possibly from the metallic state, would be easily taken up and held until the waters were forced to abandon it because of cooling or the accession of carbonates from the atmosphere or neighboring shores where disintegration was already going on.

12. *The metamorphism of ancient lake-deposits.* It is quite possible that the limonite of the lake ores should be metamorphosed and changed to hematite, and very likely that it would resemble the oölitic fossiliferous ore of the Clinton; but it does not seem probable that this theory will account for so many deposits of crystalline ore as Prof. Julien claims. Lake ores are formed largely by the action of organic matter, and we have seen that the nature of the rocks containing most of the large deposits of crystalline iron ore and the terrestrial conditions which they indicate are such as to preclude the existence of plant or animal life at the time of their accumulation. The general freedom of the ores of the Keewatin and Huronian from phosphorus and sulphur is

another reason why they cannot have originated in this way, since these are both found to a considerable extent in the Scandinavian lake ores.

13. *Violent abrasion and transport.* This theory of Whitney's has been discussed by Lesley, Julien and Wadsworth, and their remarks upon it will be found under the former two names in their proper place in the Bibliography. So far as we know it has not been adopted by any geologists, nor does it appear that Whitney intended it to account for any large deposits of iron ore.

14. *Concentration and metamorphism of iron-sands.* The first to propose this explanation of the origin of iron ore beds seems to have been Mr. B. J. Harrington, in the report of progress of the Canadian Geological Survey for 1873 *. The opinion there expressed is as follows: "It seems possible that, in some cases, beds may have been formed by the accumulation of iron sands, just as they are forming in the gulf of St. Lawrence to-day, the material being derived from the disintegration of pre-existing crystalline rocks. Such beds we should expect to contain not only magnetite but ilmenite, and it is well known that in many cases ores, on being pulverized, may be more or less completely separated into a magnetic portion, containing little or no titanitic acid, and a non-magnetic portion consisting essentially of ilmenite. It seems, however, probable that in general their origin has been similar to that of the modern bog and lake ores."

This view Prof. A. A. Julien has adopted and elaborated. He has imagined that "the conditions (of the Huronian ores and their formation) consisted of a shore of some quartzose rock, rich in magnetite, whose debris the waves and currents strewed over the sea-bottom, alternately with thin sheets of quartz-granules and magnetite-crystals, partially concentrating the one or the other material in numerous heaps or thicker layers.

In the progress of the metamorphism and contortion to which the layers were subjected, their compact and lenticular forms were further developed, the magnetic oxide was further oxidized, partially as martite, or completely as specular ore (as already suggested by Brooks, Credner, and others), and assumed, at points where the contortion and pressure became intense, the micaceous structure and brilliant lustre of micaceous iron ore, by a process similar to that which produces 'slickensides.'

*Previously to this however, in 1865, J. P. Kimball had advanced views of the origin of part of the iron ores of Michigan which contained the idea set forth later by Harrington and Julien. Speaking of ferruginous conglomerates of the region he said: "They seem to be of littoral formation and to have been derived from dismembered and crumbled deposits of successive laminae of jasper and iron ore." He hardly went so far as to conclude that the shore detritus was reduced to sand, since much of the conglomerate is more like a breccia, but the idea of beach accumulations subsequently consolidated and incorporated in the later strata was plainly expressed.

The concentration of nearly pure magnetite in the deposits enclosed in the lower Laurentian strata of Canada and the Adirondacks, and of titaniferous magnetite or menaccanite in the huge ore-beds associated with the anorthosites of the upper Laurentian in both regions, point unmistakably to mechanical separation of ferriferous sediments from different terranes; *i. e.*, in the one case from the magnetitic gneiss, in the other from the traps and anorthosites, rich in menaccanite. An examination of thin sections of diabase from dykes cutting pure magnetites in Essex county, N. Y., showed this rock to be rich in menaccanite and a possible source of such sediments.

No concentration of titanitic acid has ever been found in limonites or bog-ores. These facts seem significant of the insufficiency of any chemical theory to account for the origin of all the iron ores."

Iron ore deposits formed in the manner indicated above would at present be found in sedimentary or metamorphic rocks, but in no case inclosed in eruptive rocks. As Prof. Julien says: "The rock-strata, associated with all these varieties (of iron ore), are undoubtedly of marine origin." But the titaniferous iron ores are found invariably in rocks of admitted eruptive origin. The anorthosites of the "Upper Laurentian," to which he refers, are the analogue of the titaniferous gabbro and associated gneisses of Minnesota. Prof. Julien himself says titanitic acid is not found in limonites or bog ores; but we go still farther and say that we believe that there are no deposits of titanium-bearing magnetite yet known, which cannot be shown to be of eruptive origin. The evidence for that statement is derived from an examination of many hundred analyses and the examination of a great many iron ore deposits, as well as by comparison with published descriptions of all other regions.

The titaniferous ores are therefore excluded from this category, and the only other iron ores claimed by the upholders of this theory as examples of ores formed in this way are "the deposits enclosed in the Lower Laurentian strata of Canada and the Adirondacks."

The rocks of this terrane are the oldest rocks known to geology. There may have been earlier formed strata or massive rock-bound coasts which were disintegrated and whose mineral constituents were able to furnish the iron ore now found in the Lower Laurentian. But until it is proved that such rocks did exist and that they could have furnished the sands and iron ore for the oldest deposits now known, we cannot place any great weight upon their merely conjectured existence and nature.

Again, as already remarked, under No. 4, this theory does not account for the origin of the ore, but leaves the essential question still unanswered, viz: the genesis of the original iron-bearing rock which gave off the debris to form the iron-sand.

There can be no question that in the Marquette iron district is a great fragmental stratum made up, as described by Kimball, and as accepted by Julien, of debris consisting largely of iron ore, presenting the characters of a littoral accumulation. Some portions of this stratum are found to be so largely composed of iron ore that considerable quantities have been used for merchantable ore. But it has been found that this stratum is no part of the iron formation of the country. It is the conglomeratic lower portion of an unconformable wide-spread quartzite and conglomerate formation which everywhere manifests the same tendency to take on the characters of the older rocks on which it may happen to lie. In the iron region it is made up largely of iron-ore debris. Any theory applicable to it may not be applicable to the true iron ore formation that unconformably underlies it.

15. *True veins formed by chemical segregation or secretion.* This is a relic of the early days when all ore deposits were supposed to be in veins of one kind or another, having a deep-seated connection with the centre of the earth. It is, however, not the worst form of that theory, for veinlets of iron ore are found in many iron ore deposits where cracks and crevices of different age and size have been filled up by infiltration and chemical deposition. In a few cases quite considerable fissures have been filled in this way with limonite or with hematite and siderite, but it is seldom the case that deposits of magnetite or specular hematite are found to have the characteristics of true veins. It is true that the miners almost universally speak of "hanging walls" and "foot walls," of "horses" of rock and of "faults." But these terms must all be used in an accommodated sense, when they are not entirely inapplicable. Many of them were imported to this country by the miners of Cornwall, and their persistent use has often been the cause of mistaken ideas of the true structure and origin of the ores to which they have been applied. It can be questioned whether there is any known merchantable deposit of iron ore that originated in the manner of a true segregated vein.

16. *Electro-telluric action, i. e.,* as a result of the reactions and decompositions produced by electro-magnetic currents in the earth. The rather vague processes supposed to transpire in the earth's strata on account of electric currents, have at times been invoked to account for ore deposits of all kinds. This was principally before

the working of electrical forces was as well understood as at present. The name of Mr. R. W. Fox is inseparably connected with this theory, as he made quite a hobby of it, and maintained its validity for many years in the early part of this century. He supported his arguments by many experiments demonstrative of the decomposing power of electric currents. His theory was accepted by some of the early English geologists. W. J. Henwood and Professor Reich pointed out many objections to Fox's theory and it has seldom been seriously considered in recent years.

Dr. Carl Barus in a paper read before the American Institute of Mining Engineers in 1884 gives many clear ideas on the subject. He says: "There can be little doubt that the hypothesis which ascribes to ore-currents a hydro-electric origin is perfectly correct." But he found that the electro-motive forces are so weak that it is difficult if not indeed impossible to arrive at a correct estimate of the effect really produced in this way.

In this connection, of course, the disturbing action exerted upon the compass by deposits of magnetite is to be remembered. This power of magnetite is frequently the only thing which leads to its discovery, buried as it often is under several feet of soil or drift material. R. Thalen made some interesting observations on this means of discovering bodies of iron ore. "He found that the lines of equal magnetic intensity, in the vicinity of the ore deposit, contracted to two sets of closed curves, disposed with reference to two very satisfactorily indicated *foci*." It is not very clear how the present magnetic activity of iron ore bodies can be made to explain in any way their origin.

17. *Substitution of ferrous oxide for lime in the original rock and change to peroxide.* This secondary process has been shown to be a natural and easy method of accounting for accumulations of iron ore in rocks which were originally carbonates. It was suggested in the 15th Minnesota Report (p. 246) as the probable origin of the Keewatin ores at Tower. It is somewhat allied to No. 4, but involves also the carrying of iron in solution to take the place of the removed calcium carbonate. This theory may very properly be applied to ores of comparatively recent date whose environments indicate the former existence of a carbonate in the rock; but the Laurentian and Keewatin rocks proper are not found to contain limestones which could have been acted upon in this way, and such limestones as they do contain show no indications of such transitions. Indeed, the nature of these rocks indicates that in Minnesota the environments were such that deposits of carbonates of lime and iron could scarcely have been precipi-

ated abundantly, much less acculated mechanically at the time the rocks were formed.*

In any case the source of the iron which may thus have been substituted for lime is not satisfactorily accounted for, though perhaps it would not be difficult to do so. This theory is applicable as urged by Irving and Van Hise, to the ores of the Huronian Taconic) in the lake Superior region.

18. *Secondary product from the decomposition of basic rocks, eruptive or metamorphic, and concentration of the oxide of iron in drainage basins.* Although this idea was suggested or implied in the descriptions of iron ore deposits, by several geologists, and although the decomposition of basic rocks is understood by all to furnish the iron which is now being accumulated in marshes and bogs, yet there is but one or two who have insisted upon it as explanatory of deposits of crystalline ores. It is indicated by Dr. A. Schmidt as being part of the process of formation of the iron ore deposits of Missouri. Mr. J. P. Kimball has given the clearest statement of this method of formation in the older rocks. It is as follows: "The large bodies of hematite or specular oxide, together with associated ferruginous aggregates, in part, of magnetic oxide, are secondary products from the decomposition of basic eruptive rocks, now represented by the epidotic diorite, which has penetrated and overflowed the syenitic base of this part of the Sierra Mæstra. They are the result of the alteration or epigenesis of highly basic, and therefore unstable rock-aggregates, and of their resolution into new aggregates with the aid of surface agencies, in subordination to the new conditions met with at and near the surface. Thus the presence of oxygen in atmospheric air, and of alkaline and earthy bicarbonates from decomposing silicates, has rendered unstable the highly ferriferous material from deep-seated sources. These aggregates were basic from excess of protoxide bases, and especially protoxide of iron. Such eruptive material cannot long resist further oxidation at the surface, with the result of more or less complete disintegration of the original aggregate, and its recomposition into new compounds. . . . To be more specific, the eruptive material which gave origin to the iron ore consisted of proto-silicates, or silica combined with the protoxide bases, iron, lime and magnesia, and with alumina. Under its new conditions at the surface, with access to oxygen in the atmosphere and in circulating waters, and in contact with bi-carbonates of the alkalies and of alkaline earths, (also circulating in meteoric waters, and derived

*The so-called Laurentian limestones of Canada are apparently an anomalous exception; but there is reason for suspecting that they may not be of Laurentian age.

in part from itself, but especially furnished in large proportion by still more feldspathic material like syenite in the process of weathering), the protoxide of iron became rapidly further oxidized into ferric or sesqui-oxide, which is a comparatively stable product under conditions prevailing at the surface. The oxidation of the ferrous to ferric oxide is attended with more or less complete dismemberment of the eruptive rock, little by little. Silica originally combined with the ferrous oxide is isolated as silica. Silicates of lime, magnesia and alumina, being more stable, form new aggregates among themselves, in part according to atomic proportions."

This outline of the method of the extraction and concentration of iron oxide is correct and valuable, as it gives hints of the chemistry involved, some of which is similar in its reactions to those changes which are supposed by the writers to have taken place in the oceanic waters of the time of the Keewatin. This theory as presented by Dr. Kimball is probably quite valid for the surface deposits of iron ore to which it was directly applied, but there are various reasons why it cannot apply without considerable exception to those of Michigan, Wisconsin and Minnesota. From what has gone before these reasons will easily suggest themselves to the reader, *e. g.*, the fact that the rocks of the Keewatin have not undergone much decay since they were cleanly abraded by glacial action, and that the iron ore bodies sustain such intimate relations with the enclosing rocks as to afford good evidence that they were deposited contemporaneously. The work of decomposition and solution and recombination and precipitation must have gone on in the heated waters of the ocean, which would have an effect similar in some respects to that of percolating atmospheric waters, but much more intense and on a vastly larger scale.

The hypothetical *origination* of the ore, under this theory is, however, identical with that adopted by the writers. The chief difference consists in this: That Kimball supposes the ore to be not indigenous in the rock in which it is found, but a secondary product. We suppose the iron ore of the Keewatin to be indigenous, and one of the coëval constituents of the rock in which it occurs. He postulates some secondary, superficial "drainage basins", subject to meteoric agencies. We only need the ocean, and the same forces as those that originated the rocks of Keewatin time.

CONCLUDING OBSERVATIONS.

From a perusal of the foregoing it will be seen that of the eighteen distinct methods which have been proposed to explain the accumulation of ferric oxide in massive deposits, eight or ten are

based on sound chemistry and a correct interpretation of physical facts and may be valid theories for some particular deposits of ore. It is also seen that the general tendency of opinion has been away from Hutton's theory of igneous injection or eruption toward the various chemico-sedimentary theories, and that of these the theories receiving the most general support are numbers eight and eleven, *derivation from original deep sea deposits and metamorphism of ancient bog-ores*. It is also evident that no thoughtful person can ever again attempt to explain all deposits of iron ore on any one theory, because iron is a metal of such wide distribution and ready chemical affinity, and of such varied forms of combination that it may be acted upon by every agent of solution or decay, as well as of precipitation or mechanical deposition.

Another result that has been made clear, based upon evidence of incontrovertible fact and weighty opinion is that organic matter is no more necessary for the production of iron ore beds than it is for the formation of beds of quartzite, and that iron ore accumulations in the Archæan rocks are no indication whatever of the existence of animal or vegetable life at that period of the world's history. This idea springing from the observed action of organic matter in the formation of bog ores, has had the same history as those that sprung from other limited observation and study. It has been used to account for all iron ores. It has to be restricted to the limits which its very limited applicability can be said to establish.

On the whole we believe that a review of the various theories held at different times upon this subject shows that there has been in recent years a great advance, and an approach to more generally correct understanding of the ways in which iron ore may have been accumulated in the past and is being formed at present.

A tabulated list of the various advocates of the eighteen theories discussed in the foregoing pages is placed here for the purpose of showing at a glance what geologists have supported the different views. By reference to the bibliography which follows, the place where each opinion referred to was published may be found, and often a direct quotation bearing upon the point in question.

LIST OF ADVOCATES OF THE VARIOUS THEORIES.*

- Theory No. 1.*
 C. J. B. Karsten, 1853.
 (Cerro de Mercado.)
 A. E. Nordenskiöld, 1872.
 G. Tschermak, 1874.
- Theory No. 2.*
 L. Moro, 1740.
 J. Hutton, 1795.
 W. W. Mather, 1839.
 Le Play, 1844.
 Sir R. Murchison, 1845.
 Burat, 1845.
 Elie de Beaumont, 1847.
 Durocher, 1849.
 Foster & Whitney, 1851.
 T. Andrews, 1852.
 Fr. C. L. Koch, 1853.
 J. D. Whitney, 1855.
 E. Emmons, 1856.
 Dr. Deck, (Beck?) 1857.†
 H. D. Rogers, 1858.
 H. Weidner, 1858.
 B. Von Cotta, 1864.
 S. H. Daddow, 1866.
 Benj. Bannan, 1866.
 Chas. Whittlesey, 1867.
 †Walter Flight, 1875.
 J. C. Smock, 1875.
 A. Daubrée, 1875.
 †K. J. T. Steenstrup, 187
 G. Fabre, 1876.
 A. Sjögren, 1876.
 Jos. Szabo, 1876.
 Tombeck, 1876.
 †Chancourtois, 1877.
 †Rohde, 1877.
 J. W. Dawson, 1878.
 †J. L. Smith, 1878.
 M. E. Wadsworth, 1880.
 †J. W. Judd, 1881.
 P. Frazer, 1883.
 †H. Hensoldt, 1889.
- Theory No. 3.*
 Lehmann, 1753.
 Prof. Necker, 1832.
 Dufrenoy, 1834.
 Douglass Houghton, 1841.
 Le Play, 1844.
 Burat, 1845.
 Elie de Beaumont, 1847.
 Durocher, 1849.
 Foster & Whitney, 1851.
 J. D. Whitney, 1855.
 E. Emmons, 1856.
 B. Von Cotta, 1864.
- O. A. Corneliusen, 1877.
 J. W. Dawson, 1878.
 Eugene Costé, 1887.
- Theory No. 4.*
 R. M. S. Jackson, 1838.
 L. Vanuxem, 1838.
 G. Bischof, 1847.
 Chas. Whittlesey, 1867.
 J. P. Lesley, 1867.
 T. B. Brooks, 1873.
 R. Pumpelly, 1873.
 J. W. Harden, 1874.
 C. Le Neve Foster, 1875.
 S. F. Emmons, 1876.
 A. Firket, 1878.
 Eugene A. Smith, 1878.
 C. E. Wright, 1879.
 H. C. Lewis, 1880.
 M. E. Wadsworth, 1880.
 J. P. Kimball, 1884.
 C. R. Van Hise, 1889.
- Theory No. 5.*
 L. Vanuxem, 1838.
 J. M. Safford, 1856.
 B. Von Cotta, 1864.
 A. Schmidt, 1872.
 J. P. Kimball, 1884.
- Theory No. 6.*
 Elie de Beaumont, 1847.
 Durocher, 1849.
 Von Dechen, 1851.
 J. M. Safford, 1856.
 H. D. Rogers, 1858.
 B. Von Cotta, 1864.
 A. Schmidt, 1872.
 F. Prime, Jr., 1875.
 C. R. Alder Wright, 1885.
- Theory No. 7.*
 C. U. Shepard, 1837.
 G. Bischof, 1847.
 H. D. Rogers, 1858.
 T. S. Hunt, 1869.
 P. Frazer, 1875.
 F. Prime, Jr., 1875.
 S. F. Emmons, 1876.
 A. Firket, 1878.
 H. C. Lewis, 1880.
- Theory No. 8.*
 Dr. E. Hitchcock, 1833.
 C. U. Shepard, 1837.
- J. W. Foster, 1849.
 J. D. Whitney, 1855.
 W. W. Smyth, 1856.
 H. D. Rogers, 1858.
 B. Von Cotta, 1864.
 J. P. Lesley, 1866.
 B. S. Lyman, 1867.
 Chas. Whittlesey, 1867.
 A. Winchell, 1870.
 C. Le Neve Foster, 1875.
 F. Prime, Jr., 1875.
 H. Credner, 1875.
 A. Sjögren, 1876.
 C. E. Wright, 1879.
 W. O. Crosby, 1879.
 M. E. Wadsworth, 1880.
 J. A. Phillips, 1884.
 C. R. Alder Wright, 1885.
 R. D. Irving, 1886.
 C. R. Van Hise, 1889.
 N. H. Winchell & H. V. Winchell, 1889.
- Theory No. 9.*
 G. Bischof, 1847.
- Theory No. 10.*
 W. B. Rogers, 1857.
- Theory No. 11.*
 Robt. Bakewell, 1833.
 Dr. W. Kitchell, 1856.
 Hausmann, 1860.
 Geo. H. Cook, 1868.
 T. S. Hunt, 1869.
 B. J. Harrington, 1873.
 J. D. Dana, 1874.
 O. Gumælius, 1875.
 J. S. Newberry, 1875.
 Jos. Le Conte, 1878.
 A. Geikie, 1882.
 Jeremiah Head, 1887.
- Theory No. 12.*
 Hausmann, 1860.
 Ed. Hull, 1876.
 A. A. Julien, 1882.
- Theory No. 13.*
 J. D. Whitney, 1855.
- Theory No. 14.*
 J. P. Kimball, 1865.
 B. J. Harrington, 1873.
 A. A. Julien, 1882.

*For a statement of these theories see page 224.

†Metallic iron in Basalt.

‡See Lesley, Iron Manufacturer's Guide, page 407.

Theory No. 15.

F. W. Smyth, 1858.
 B. Von Cotta, 1864.
 Ed. Hartley, 1867.
 A. Schmidt, 1872.
 P. Wurzburger, 1874.
 J. H. Collins, 1875.
 C. R. C. Tichborne, 1877.
 C. R. Alder Wright, 1885.

Theory No. 16.

R. W. Fox, 1822.

Becquerel, 1835.
 H. T. De La Beche, 1839.
 Man. De Castro, 1878.

Theory No. 17.

G. Bischof, 1847.
 A. Schmidt, 1872.
 J. D. Kendall, 1874.
 W. H. Hudleston, 1875.
 P. N. Moore (no date).
 J. P. Kimball, 1884.
 N. H. Winchell, 1886.
 I. C. Russell, 1889.

Theory No. 18.

A. Schmidt, 1872.
 J. P. Kimball, 1884.
 N. H. Winchell and
 H. V. Winchell, 1889.

PART V.

BIBLIOGRAPHY OF THE ORIGIN OF IRON ORES.

NOTE.

So far as known this is the first attempt at a bibliography of the origin of iron ores. It contains, besides the titles of articles and books treating directly and exclusively of the origin of iron ores, the titles of many works that refer only incidentally to their origin, and of others that do not discuss their origin at all. It was considered useful to list such because of their value and authority on some of the aspects of iron ore, or because of their treatment of the phenomena of its physical structure which is inseparably connected with any inquiry into their origin. Many of these works have not been seen, particularly those published in foreign countries, and their titles have been copied from other references, principally from the "Geological Record," London, 1875 to 1889. The list cannot be considered complete, but it contains every title that has fallen under our notice, and is more nearly complete for works published since 1872.

There are some smaller papers in such publications as the bulletins of the United States Census, of the American Iron and Steel Association, Iron, and the Engineering and Mining Journal, and others, that are here generally not included.

List of Abbreviations.

- A. A. A. S. American Association for the Advancement of Science.
Acad. Sci. Berlin. Academy of Science, *Berlin.*
Am. Assoc. Adv. Sci. American Association for the Advancement of Science.
Am. Chem. Jour. American Chemical Journal. *Baltimore.*
Am. Geol. American Geologist. *Minneapolis.*
Am. Inst. Min. Eng. American Institute of Mining Engineers.
Am. Jour. Sci. American Journal of Science and Arts. *New Haven.*
Am. Nat. American Naturalist. *Philadelphia.*
Ann. de Chimie. Annales de Chimie et de Physique. *Paris.*
Ann. Lyc. Nat. Hist. Annals of the Lyceum of Natural History. *New York.*
Ann. Mines. Annales des Mines. *Paris.*
Ann. Rep. Brighton Nat. Hist. Soc. Annual Report of the Brighton and Sussex Natural History Society. *Brighton.*
Ann. Sci. Disc. Annual of Scientific Discovery.
Ann. Soc. Géol. Belg. Annales de la Société Géologique de Belgique. *Liège.*
Ann. Soc. Géol. d'Nord. Annales de la Société Géologique du Nord. *Lille.*
Atti. Soc. Ital. Sci. Nat. Atti della Società Italiana di Scienze Naturali. *Milan.*

- Berg. u. Hüttenm. Zeit.* Allgemeine berg- und hüttenmännische Zeitung
 Quedlinburg.
- Berk. Hist. and Sci. Soc.* Berkshire Historical and Scientific Society.
- Bihang K. Svenska Vet.-Akad. Handl.* Bihang till det Kongliga Svenska
 Vetenskaps-Akademiens Handlingar.
- Bol. Com. Map. geol. Espan.* Boletín de la comision del Mapa geologico de
 Espana. Madrid.
- Boll. R. Com. geol. Ital.* Reale Comitato geologico d' Italia. Bollettino.
 Rome.
- Brit. Assoc. Adv. Sci.* British Association for the Advancement of Science.
- Bull. Am. Iron Steel Assoc.* Bulletin of the American Iron and Steel Asso-
 ciation.
- Bull. Mus. Comp. Zool.* Bulletin of the Museum of Comparative Zoology,
 Harvard College. Cambridge.
- Bull. Soc. Etud. Sci. Angers.* Bulletin de la Société des Etudes Scientifiques
 d'Angers.
- Bull. Soc. Géol. France.* Bulletin de la Société Géologique de France.
 Paris.
- Bull. Soc. Géogr.* Bulletin de la Société de Géographie. Paris.
- Bull. Soc. Ind. Min. St. Etienne.* Bulletin de la Société de l' Industrie min-
 érale de St. Etienne.
- Bull. Soc. Sci. Nat. Neuchatel.* Bulletin de la Société des Sciences Natur-
 elles de Neuchatel.
- Bull. Soc. Sci. Nat. Sud Est.* Bulletin de la Société des Sciences Naturelles
 du Sud-Est. Grenoble.
- Canad. Journ.* The Canadian Journal of Science, Literature and History.
 Toronto.
- Can. Nat. and Geol.* Canadian Naturalist and Quarterly Journal of Science.
 Montreal.
- Chem. News.* The Chemical News and Journal of Physical Science. Lon-
 don.
- Coll. Guard.* The Colliery Guardian and Journal of the Coal and Iron Trades.
 London.
- Compt. Rend.* Comptes Rendus hebdomadaires des Séances de l'Académie
 des Sciences de l'Institut de France. Paris.
- Compt. Rend. Soc. Ind. Min.* Comptes Rendus mensuelles des réunions de
 la Société de l' Industrie Minérale de St. Etienne.
- Corr-Blatt. Nat. Ver. preuss. Rheinl.* Correspondenz-Blatt des naturhisto-
 rischen Vereins der preussischen Rheinlande und Westfalens. Bonn.
- Emul. Jurass.* L'Emulation Jurassienne. Delémont.
- Eng. Min. Jour.* The Engineering and Mining Journal. New York.
- Ex. Docs.* Executive Documents published by the United States Govern-
 ment. Washington.
- Földt. Közl.* Földtani Közlönye (Geological Magazine.) Budapest.
- Geol. Fören. Stockholm Förhandl.* Geologiska Föreningens i Stockholm
 Förhandlingar. Stockholm.
- Geol. Mag.* The Geological Magazine or Monthly Journal of Geology. Lon-
 don.
- Geol. Nat. Hist. Sur. Minn.* Geological and Natural History Survey of Min-
 nesota. Minneapolis.
- Geol. Can. or Geol. Sur. Can.* Geological Survey of Canada. Ottawa.
- Geol. Rec.* Geological Record. London.
- Geol. Sur. Mich.* Geological Survey of Michigan.
- Geol. Trans.* Transactions of the Geological Society. London.
- Gornoy Journ.* Gornoy Journal, izdavaemy Uchenim Komitetom, Korpus
 Gornikh Injenerov. St. Petersburg.

Iron. Iron, The Journal of Science, Metals and Manufactures. *London.*

Jaarb. Mijn. Ned. O.-Ind. Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië. *Amsterdam.*

Jahrb. k. k. geol. Reichs. Jahrbuch der kaiserlich-königlich geologischen Reichsanstalt. *Vienna.*

Jahresh. Ver. Nat. Württ. Jahreshefte des Vereins für Vaterländische Naturkunde in Württemberg. *Stuttgart.*

Journ. Iron Steel inst. Journal of the Iron and Steel Institute. *London.*

Journ. R. Geol. Soc. Ireland. Journal of the Royal Geological Society of Ireland. *Dublin.*

Journ. Soc. Arts. Journal of the Society of Arts. *London.*

Journ. U. S. Assoc. Charcoal Iron Workers. Journal of the U.S. Association of Charcoal Iron Workers. *Harrisburg.*

Kansas City Rev. Sci. Ind. The Kansas City Review of Science and Industry.

Karst. Archiv. Karsten's Archives.

Kent Nat. Hist. Soc. Kent Natural History Society. *Grand Rapids.*

Math. Természet Közlem. Matematikai és Természettudományi Közlemények, vonatkozólag a hazai viszonyokra. *Budapest.*

Mem. Geol. Sur. Memoirs of the Geological Survey of Great Britain.

Mem. Geol. Sur. Ind. Memoirs of the Geological Survey of India. *Calcutta.*

Metall. Rev. The Metallurgical Review. *New York.*

Min. Journ. Mining Journal. *London.*

Min. Mag. The Mineralogical Magazine and Journal of the Mineralogical Society of Great Britain. *London.*

Min. Mitth. Mineralogische und petrographische Mittheilungen. *Vienna.*

Mitth. nat. Ver. Maja. Mittheilungen des naturforschenden Vereins Maja. *Clausthal.*

Nachricht. k. Ges. Wiss. Nachrichten von der königlichen Gesellschaft der Wissenschaften und der Georg-August Universität. *Göttingen.*

Nat. Hist. Phil. Soc. The Natural History and Philosophical Society.

Natl. Acad. Sci. National Academy of Science. *Washington.*

Nature. Nature, a weekly illustrated Journal of Science. *London.*

Neues Jahrb. für Min. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. *Stuttgart.*

N. Jahrb. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. *Stuttgart.*

North Am. Rev. North American Review.

Nova Acta R. Soc. Upsal. Nova Acta Regiæ Societatis Upsalensis. *Upsala.*

N. Staff. Field Club. North Staffordshire Field Club, Annual Addresses, etc.

Hanley.

Nyt Mag. Nat. Nyt Magazin for Naturvidenskaberne. *Christiania.*

Oefvers. K. Vet.-Akad. Förhandl. Oefversigt af Kongl. Vetenskaps-Akademiens Förhandlingar. *Stockholm.*

Oesterr. Zeitsch. Berg. Hütt. Oesterreichische Zeitschrift für Berg- und Hüttenwesen. *Vienna.*

Penn Geol. Sur. Pennsylvania Geological Survey. *Harrisburg.*

Phil. Mag. London, Edinburgh and Dublin Philosophical Magazine and Journal of Science. *London.*

Phil. Mag. and Annals of Phil. Philosophical Magazine and Annals of Philosophy. *London.*

Phil. Trans. Philosophical Transactions of the Royal Society of London. *London.*

Poggend. Ann. Poggendorff's Annalen.

- Politecnico. Il Politecnico. Giornale dell' Ingegneria ed Architettura Civile ed Industriale Milan.*
- Proc. Ac. Nat. Sci. Phil.* Proceedings of the Academy of Natural Sciences. Philadelphia.
- Proc. Am. Assoc. Adv. Sci.* Proceedings of the American Association for the Advancement of Science. Salem.
- Proc. Am. Phil. Soc.* Proceedings of the American Philosophical Society. Philadelphia.
- Proc. Bost. Soc. Nat. Hist.* Proceedings of the Boston Society of Natural History.
- Proc. Bristol Nat. Soc.* Proceedings of the Bristol Naturalists' Society. London and Bristol.
- Proc. Cleveland Inst. Eng.* Proceedings of the Cleveland Institute of Engineers. Middlesbrough.
- Proc. Dudley Geol. Soc.* Proceedings of the Dudley and Midland Geological and Scientific Society and Field Club. Dudley.
- Proc. Geol. and Poly. Soc. of the West Riding.* Proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire. Leeds.
- Proc. Geol. Assoc.* Proceedings of the Geologists' Association. London.
- Proc. Inst. Civ. Eng.* Minutes of the Proceedings of the Institute of Civil Engineers. London.
- Proc. Liverpool Geol. Soc.* Abstract of the Proceedings of the Liverpool Geological Society. Liverpool.
- Proc. Lyc. Nat. Hist. N. Y.* Proceedings of the Lyceum of Natural History of the city of New York. New York.
- Proc. Roy. Dublin Soc.* Scientific Proceedings of the Royal Dublin Society.
- Proc. Roy. Soc. N. S. Wales.* Proceedings of the Royal Society of New South Wales. Sydney.
- Proc. S. Wales Inst. Eng.* Proceedings of the South Wales Institute of Engineers. Swansea.
- Q. J. G. S.* The Quarterly Journal of the Geological Society of London.
- Quart. Journ. Geol. Soc.* Ditto.
- Quart. Journ. Sci. and Arts.* Quarterly Journal of Science and Annals of Mining, Metallurgy, Engineering, Industrial Arts, Manufactures. London.
- Queenslander.* The Queenslander. Folio. Brisbane.
- Rec. Geol. Sur. Ind.* Records of the Geological Survey of India. Calcutta.
- Rep. Brit. Assoc.* Report of the British Association for the Advancement of Science. London.
- Rep. Prog. Geol. Can.* Report of Progress for....., Geological and Natural History Survey of Canada. Montreal.
- Rep. Russ. Geol. Com.* Report of the Russian Geological Committee. St. Petersburg.
- Rev. Geol.* Revue de Géologie (by Delesse and De Lapparent). Paris.
- Rev. Min.* Revista Minera. Periodico Cientifico e Industrial. Madrid.
- Revista Minera.* Vid. *Rev. Min.*
- Rev. Sci.* Revue Scientifique de la France et de l'Étranger. 4to. Paris.
- Rev. Univ. des Mines.* Revue Universelle des Mines, de la Métallurgie, des Travaux Publics, des Sciences et des Arts appliqués à
- Sch. Min. Quart.* Columbia College School of Mines Quarterly. New York.
- Senate Docs.* Documents of the United States Senate.
- Sitz. k. böhm. Ges. Wiss.* Sitzungsberichte der Königlichen böhmischen Gesellschaft der Wissenschaften. Prague.
- Trans. Ac. Sci. St. Louis.* The Transactions of the Academy of Science of St. Louis.
- Trans. Am. Inst. Min. Eng.* Transactions of the American Institute of Mining Engineers. New York.
- Trans. Assoc. Am. Geol. Nat.* Transactions of the Association of American Geologists and Naturalists.

Trans. Camb. Phil. Soc. Transactions of the Cambridge Philosophical Society. 4to. Cambridge.

Trans. Chesterfield Inst. Eng. Chesterfield and Derbyshire Institute of Mining, Civil and Mechanical Engineers, Transactions. *London and Derby.*

Trans. Edin. Geol. Soc. Transactions of the Edinburgh Geological Society. Edinburgh.

Trans. Manch. Geol. Soc. Transactions of the Manchester Geological Society. Manchester.

Trans. N. Engl. Inst. Eng. North of England Institute of Mining and Mechanical Engineers, Transactions. *Newcastle-on-Tyne.*

Trans. Nova Scot. Inst. Proceedings and Transactions of the Nova Scotian Institute of Natural Science. *Halifax, N. S.*

Trans. N. Y. Acad. Sci. Transactions of the New York Academy of Sciences. New York.

Trans. N. Zealand Inst. Transactions and Proceedings of the New Zealand Institute. Wellington.

Trans. Roy. Geol. Soc. Cornwall. Transactions of the Royal Geological Society of Cornwall. *Penzance.*

Trans. Roy. Soc. Can. Transactions of the Royal Society of Canada. 4to. Montreal.

Trans. Roy. Soc. Edinburgh. Transactions of the Royal Society of Edinburgh. 4to. Edinburgh.

Trans. Wisc. Acad. Sci. Transactions of the Wisconsin Academy of Sciences, Arts and Letters. *Madison.*

Verh. k.-k. geol. Reichs. Verhandlungen des kaiserlich-königlichen geologischen Reichsanstalt. *Vienna.*

Verh. Nat. Ver. Brünn. Verhandlungen des Naturforschenden Vereins zu Brünn. *Brünn.*

Verh. nat. Ver. preuss Rheinl. Verhandlungen des naturhistorischen Vereins des preussischen Rheinlande und Westfalens (including *Sitzungsberichte* and *correspondenz-Blatt.*) *Bonn.*

Wis. State Agr. Soc. Trans. Transactions of the Wisconsin State Agricultural Society.

Zeit. deut. geol. Gesells. Zeitschrift der deutschen geologischen Gesellschaft. *Berlin.*

Zeitsch. Berg.-Hütt. Salinenw. Zeitschrift für das Berg-, Hütten- u. Salinenwesen im preussischen Staate. *Berlin.*

Zeitsch. berg.-hütt. Ver. Kärnten. Zeitschrift des berg- und hüttenmännischen Vereins für Steiermark und Kärnten. *Klagenfurt.*

Zeitsch. gesamt. Nat. Zeitschrift für die gesammten Naturwissenschaften. Original abhandlungen und monatliches Reportorium der... Geologie, Oryctognosie, Paläontologie. *Berlin.*

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Explains lodes as being essentially products of volcanic emanations; these he subdivides into igneous-fluid (injections), gaseous (sublimations), and aqueous (infiltrations by means of hot mineral springs).

Becher, J. J. *Physica Subterranea.* Frankfurt, 1669.

Beck, Lewis C. *Natural History of New York.* Pt. III, Mineralogy, pp. 1-40, 1840.

Describes hematite and magnetite as occurring in *beds* and sometimes in veins. On p. 3 he says:

"The magnetic iron ore in these counties is, with scarcely an exception, in what is usually termed *beds*, or deposits of variable widths and unknown depths running parallel to the course of the stratification, when the rock is stratified. The general direction of these beds is northeast and southwest, but when subject to local variations the course is north and south or north-northeast and south-southwest.

Sometimes, however, the ore occurs in large masses in the rock without any regular parallelism of the sides, as is the case in Essex county. And lastly, it is disseminated in particles in the rock, apparently without any connection with a bed or vein."

Bequerel, ———. *Traité Experimental de l'électricité et du Magnétisme*, tom. iii, Paris 1835.

"Bequerel considers that to a certain depth in the earth a multitude of electric currents exist, with very different directions, the general result of which would produce an action on the magnetic needle. He considers these currents would be caused by the permanent communication kept up by means of numerous fissures through which the sea-waters percolate either to the metals of the earths and alkalis or to metallic chlorides, causing the metals to take negative electricity, and the steam and other vapors positive electricity. One part of the latter electricity, he infers, would be carried into the atmosphere by volcanic eruptions, and the other would tend to combine with the negative electricity of the bases, by passing through all the conducting bodies which established the communication between the metals or their chlorides, and the solid, liquid or gaseous substances which filled the fissures. Hence, he observes, a number of partial electrical currents would circulate in the interior of the globe, producing electro-chemical reactions, of which we cannot appreciate the whole extent, but which certainly would give rise to numerous compounds."

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Berthoud, E. L. On the Occurrence of Uranium, Silver, Iron, etc., in the Tertiary Formation of Colorado. *Proc. Ac. Nat. Sci. Philadel.* pt. ii., pp. 363-366. 1875.

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"The iron ores of this Province are chiefly confined to the Laurentian system of rocks, in which they occur in such prodigious quantities that this may be styled pre-eminently the iron formation. The origin of these ores we know not. It is only certain that during the period when the Laurentian rocks were in process of being formed, iron was abundantly elaborated, while in the age of the Huronian deposits copper was principally produced and iron not at all in any great quantity."

Birkinbine, John. [Cerro de Mercado Iron Ore Mass, Durango, Mexico.] *Chicago Mining Jour.*, vol. ii, p. 184, 1882.

———. Iron Ores of Tennessee. *Journ. U. S. Assoc. Charcoal Iron Workers*, vol. iv, No. 2, p. 82, 1883. Taken from the *Hand-Book of Tennessee*, published by the Bureau of Mines.

———. Cerro de Mercado (Iron Mountain) at Durango, Mexico. Report to W. L. Helfenstein, President of the Iron Mountain Company of Durango, Mexico. *Trans. Am. Inst. Min. Eng.* 1884.

"I incline to the belief that the *Cerro de Mercado* is formed of one or more immense veins or lenses of specular iron ore, standing nearly vertical, the fragments of which have, by the actions of the elements for ages, been thrown down to form the slopes of the mountain as a talus; but the extent of this detrital ore is too great to permit of locating any foot or hanging walls."

———. The Iron Ores East of the Mississippi River. *Mineral Resources of the U. S.* 1886, p. 50.

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———. Elements of Chemical and Physical Geology. *Cavendish Society's Publications*, vol. iii, 1853; pp 521, 543.

"Oxide of iron is in all instances the product of decomposition of ferruginous minerals, and since almost all minerals constituting rocks contain some iron, it may originate from the most diverse sources. * * * The frequent occurrence of red and brown hematite in limestone, the transition of one into the other, and the presence of the same fossil remains in the iron ores as in the limestone, lead to the conclusion that many deposits of iron ore have originated by the displacement of the carbonate of lime. * * * There is no doubt that the ores of iron and manganese have originated from the decomposition of silicates of these metals, for they always occur in rocks that are rich in such silicates. Weissenbach states, that near Johanngeorgenstadt, the hematite lodes generally follow the junction of the granite and mica schist, and they extend into the latter only as ferruginous clay and slate. There is no doubt that in this instance the iron ores originated from the mica schist that is so rich in silicates of iron and which is somewhat decomposed near the lodes. But the products of this decomposition are found separately in the lodes, the quartz being the first, and the brown hematite the second member. This separation may be easily accounted for, when it is remembered that the small amount of carbonic acid contained in water would be in the first instance consumed in effecting the decomposition of the silicates. The water thus deprived of its carbonic acid could not dissolve the carbonate of iron that had been produced, but it could exercise the same solvent action upon the silica that had been eliminated as water containing carbonic acid. Consequently it removed the silica and deposited it in the lode fissures. When the decomposition of the silicates of iron was so far advanced that carbonic acid was no longer consumed in this way, the carbonate of iron would be dissolved and carried into the lode, where, according as there was or was not access of atmospheric air, it would be deposited as hydrated peroxide or as carbonate of iron."

———. *Lehrbuch der Chemischen und Physicalischen Geologie*, Bonn, 1854, vol. ii, p. 1325.

"All iron ores in ganges or layers are either immediate deposits from water or are deposited from such by the removal of other substances. There is no rock sediment in fact wholly free from protoxide of iron. Even in the variegated red sandstones I have found remarkable quantities. Plenty of material is at hand therefore, in the adjoining strata for even such vast beds as those of Schlettenbach and Bergzabern in Rhein-baden. Should a rock contain nothing but peroxide, organic substances will reduce this to protoxide and the developing carbonic acid will convert this again into carbonate of iron. Never has an iron gangue been filled by sublimation. The sublimation of iron in Vesuvius is a local exhibition, impossible, as Mitscherlich showed (Poggend. Ann. B. xv, S. 630) without the help of water. Iron ores change into each other, but never into other minerals. All of them are products of the decomposition of iron-holding minerals, and as scarcely any mineral is not iron-holding any mineral may form an iron ore bed. * * * The oxide and especially the protoxide of iron are strong bases closely related to and easily with moderate heat uniting with silicic acid, as is seen in blast furnace processes, when, for instance, copper smelters add quartz minerals to get a fluid slag from the protoxide of iron and silica, or when welders sprinkle fine sand on the end of the iron to be welded, to turn thereby the coating of the protoxide into a silicate slag which every blow of the sledge removes and lets the pure iron come face to face. See then from these examples how impossible it would be to find quartz and magnetic iron separate if they were of igneous origin. Yet at Arendal the ramifications of magnetic iron penetrated the syenite and granite walls, while bands and veins swarm along the bed-planes and cleavage lines of the gneiss. As little can the magnetic ore result from a metamorphosis of the gneiss plutonically. And if syenite and granite were igneous rocks it were impossible for magnetic iron to separate from them. Wet segregation alone remains." (Lesley, Iron Mfrs. Guide.)

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phique et paléontologique. *Bull. Soc. Géol. France* sér. 3, t. xii, pp. 46-107, 1884. *Bull. Soc. Sci. Nancy*, sér. 2, t. vi, 15 Ann. pp. xviii-xx 1883.

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"The E. end and higher part of the island consist of older schists, in which are the iron-mines; though connected with augitic rock, it is held that the ores themselves are not of eruptive nature. The case is parallel with that of Arendahl."

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"The suggestion made by Mr. R. D. Irving, in the American Journal of Science for October, 1886, that the ore has been washed into its present position from previously precipitated beds of carbonate seems to me very plausible, and is borne out in a large measure by the chemistry of the ore body. I should, however, suggest this change, that the original deposits of iron and lime were not as crystallized siderite and calcite, but as hydrous oxide and carbonate of lime, with intermixed calcareous deposits.

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On Iron Ores of Elba:

"Burat thinks the iron-ore must here have penetrated upwards, precisely in the same manner as igneous-fluid rocks. This supposition, he thinks, solves the whole enigma of the origin, against which indeed many important doubts may be raised." Von Cotta, Ore Deposits.

"Burat says of Rio la Marina, which was the only locality where iron was exploited in 1845; that this largest and richest iron deposit of the island, (of Elba), has penetrated, parallel to the stratification, between quartzose schist and limestone. The centre of the same consists of crystalline specular iron and compact limonite: the former contains concretions of iron pyrites. The limits, towards the hanging and foot-walls, are rendered indistinct by intermixtures and transitions. The enclosing strata have also become very crystalline near the deposits, and contain amphibole and lievrite. All the relations tend to show a sublimation or eruption. When we call to mind that on Vesuvius newly formed fissures have been filled, in the course of a few weeks, with specular iron by sublimation; this manner of formation becomes very probable for the iron-deposits of Elba, although the island does not belong to the truly volcanic ones. The apparently massive-occurrence of the specular iron can be probably traced back to a repeated fissuring and penetration of these rocks." Von Cotta, Ore Deposits, pp. 356, 357."

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Cohen, Dr. E. [Titanic Iron from the South African Diamond Fields.] *N. Jahrb. Heft* vii, pp. 695-697. 1877.

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"Red hematite and a little spathic iron occur in a true fissure-lode in the Killas, bearing N. 18° W. The author supposes the contents of the vein may have been derived from the enclosing rocks."

———. On the Great Perran Iron Lode. *Rep. Min. Assoc. Cornwall and Devon.* pp. 55-69. 1874.

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Comstock, Theo. B. First Annual Report Geological Survey of Texas 1889. pp. 347-360.

"Three different kinds of exposures (of hematites) may be made out as viewed with reference to their modes of origin. To these, for convenience, we may give names as follows: (1) *Altered Magnetites*; (2) *Concretionary Ores*; (3) *Hematite Sandstone*."

Cook, Geo. H. Geology of New Jersey, 1868. p. 61.

"The beds of iron ore are thought by many persons to be veins; and they are so called in all the regions where they are mined. This term has been applied to them by the English and German miners, who have worked *true* veins in their own countries, and are habituated to think that all metallic ores are of igneous origin, and have been forced into the positions they now occupy, in a melted state. This theory is sustained by the high authority of Prof. H. D. Rogers. Dr. Kitchell and all his assistants, after thorough examination of the mines, were entirely settled in their conclusions that the magnetic ores of New Jersey were of *sedimentary* origin, and had been deposited in beds just as the gneiss and crystalline limestone had. This too is the view of most writers and geologists of the present day.

From the observations of the present survey no other conclusion can be reached, but that the magnetic iron ores, of this state, have originated from chemical or mechanical deposits, just as our hematites and bog iron ores do now; and that they have afterwards been covered by strata of sand, clay and carbonate of lime; that with these they have since been upheaved, pressed into folds, and under the influence of pressure and water, for an immense length of time, they have undergone chemical and mechanical changes, which have brought them to their present condition. They occur both in the limestone and the gneiss; they are entirely conformable to the other rocks in stratifi-

cation: they contain laminae of gneiss, hornblende, &c., just as the rocks do, and at their edges they frequently pass from the ore to the rock by such insensible gradations that one cannot tell where the ore ends and the rock begins. Folds, offsets, etc., occur in the ores just as in the other rocks. The columnar structure of some of these ores has been thought to favor the theory of their igneous origin; but beds of *sedimentary limestone* have been seen which have the same structure."

"In short, everything in structure, position and attendant minerals, shows that the ore is in sedimentary beds, the same as the gneiss is. Disturbance since its original deposition has brought its beds on edge, and so far has made it like ore in veins; and having this resemblance its beds, by the common usage of the country, are called veins, and we may so use the word in this report. There is no difficulty in conceiving of the beds as having been formed by the deposition of the peroxide of iron, and having since lost enough oxygen to change them into magnetic oxides." (l. c. p. 333.)

"The beds of magnetic iron-ore are in layers in the strata of gneiss or limestone. They are in long narrow belts, which are parallel to the general northeast and southwest strike of the azoic rocks. They have the appearance of having been thrown down as a chemical deposit along the borders of streams or slopes, perhaps sea-shores, just as oxide of iron is now deposited from spring water when it is exposed to the air; just as bog iron-ore is now depositing in many places in southern New Jersey, or just as oxide of iron is depositing at the salt springs in New York and Pennsylvania. Such deposits are necessarily of limited extent. They do not spread out over a great area as deposits of sand or clay may, but are separated from the water in which the oxide of iron is dissolved by the action of air and the escape of carbonic acid, and as quietly precipitated along the banks of rivulets or the shores of larger bodies of water into which the springs enter." (op. cit. p. 331.)

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"A geological and physical description of the iron ore deposits discovered in 1874 not far from Bodö. The ore occurs in and between layers of mica schist and granular limestone of primitive age. Holds that the ore does not occur as layers, but owes its origin to plutonic forces, perhaps a process of sublimation—an opinion contrary to that of Gumælius." (Geol. Record.)

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He considers the iron ores and associated siliceous strata to have been slowly deposited in abyssal depths of the ocean and to have been modified by segregation since their first accumulation.

Cross, Rev. J. E. The Geology of Northwest Lincolnshire. *Quart. Journ. Geol. Soc.*, vol. xxxi, pp. 115-130, 1875.

Cunningham, Walter. Report as Mineral Agent on Lake Superior. Jan. 8, 1845. Senate Docs., 28th Cong., 2d Sess., 1844-45, vii, No. 98, 5 pp.

Czyszkowski, S. Exploration géologique et industrielle des régions ferrières de l'île d'Elbe (Italie). 8vo. *Atais.* Pp. 87, 1832.

———. [Geology of the Iron District of Canigou, E. Pyrenees.] Pp. 31, folding map, 8vo, 1879. *Paris and Alais*.

———. [Geology of the Iron District of Bilbao-Somorrostio, Spain.] Pp. 40, folding maps, 8vo. *Paris*, 1879.

———. Les Minerais de Fer dans l'écorce terrestre. *Bull. Soc. Ind. Min. St. Etienne*, sér. 2, t. xiii, and separately issued, pp. 222, with atlas, 1884.

Daddow, S. H. and Benjamin Bannan. Coal, Iron and Oil, or The Practical American Miner, 1866.

"We may refer most of our great Azoic beds of magnetic and specular ores and red oxides of iron to this (volcanic eruption) cause, and their formation to the same agencies."

Daglish, T., and R. Howse. Some Remarks on the Beds of Ironstone occurring in Lincolnshire. *Trans. N. Engl. Inst. Eng.*, vol. xxiv, pt. 1, pp. 23-33, 4 plates, 1875.

Damour, A. [Metallic Iron from Santa Catarina, Brazil.] *Compt. Rend.*, t. lxxxiv, p. 478, 1887.

Dana, James D. Note on the Azoic Age and metamorphic origin of the Iron Ore of Mexico, described on p. 309. of American Journal Science, volume xxxix, ser. 2. *Am. Jour. Sci.*, ii, xxxix, 1865, p. 358.

———. *Manual of Geology*, pp. 231, 155. 1874.

"The beds of argillaceous iron-ore (Upper Silurian) which spread so widely through New York and some of the other states west and south, could not have been formed in an open sea; for clayey iron-deposits do not accumulate under such circumstances. They are proof of extensive marshes and therefore, of land near the sea-level. The fragments of Crinoids and shells found in these beds are evidence that they were, in part at least, salt-water marshes, and that the tide sometimes reached them."

In reference to the Laurentian he states:

"Limestone strata occurred among the alternations, and argillaceous iron-ores though vastly more extensive. * * * The argillaceous iron-ore has become the bright hematite or magnetite, and it is banded by, or alternates with, schist and quartz, etc., which were once accompanying clay and sand-layers."

———. *Am. Jour. Sci.*, iii, ix, 223, 1875.

In a review of the "Geology of New Hampshire," Part I., says:

"The existence of great beds of iron ore in pre-Silurian terranes is regarded as evidence (in this following Prof. T. Sterry Hunt) of the existence during the era of abundant vegetation—on the ground that, in making marsh-beds of iron ore, the oxide of iron, when carried in by the waters, is in the state of iron-salts of organic acids. But the era was a very long one; Helmholz made the time which elapsed during the cooling from 2,000 deg. C. to 200 deg. C. 350,000,000 of years; and many more millions should be added for the continuation of the cooling down to 100 C., all of which necessarily antedated the first appearance of the simplest forms of life; and still more to reduce the temperature to 38 deg. C. (100° F.), which limit was probably reached before the close of the Archæan. And in that long era, even to its close, the atmosphere certainly contained a greatly larger proportion of carbonic acid than now, if not also other acids; and also for this reason, it had much greater density. Hence carbonic acid, which does now some of the work of iron-transportation, may have done far more then. It is surely very unsafe to conclude from the existence of those iron ore beds that the vegetation was extremely abundant, or that any then existed."

———. *Amer. Jour. Sci.*, Aug. 1877, p. 132.

———. *Amer. Jour. Sci.* (iii) xxii, pp. 320, 402, 1881.

———. Berkshire Geology, 1886, pp. 25. *Berkshire Hist. and Sci. Soc.*

"All now admit that the (limonite) ore is a secondary product: that is, that it was formed through the oxidation of iron that originally made part of minerals in the schist, or in the limestone, or else in both. * * * My own conclusion * * * is that the iron has come mainly from limestone formation and not from the schist or slate. Some of the limestone, as well as schist, contains pyrite, (or iron pyrites) a brass-colored mineral consisting of 46.7 per cent of iron and 53.3 of sulphur. But we are sure that this is not the source of the iron of these beds, because there is ordinarily very little pyrite present in either the schist or limestone; and secondly, because the ore is peculiarly free from sulphur. * * * How did the iron get into the limestone? Why is it in that part of the limestone which is within a hundred yards of the schist? Why is it distributed with so great irregularity, here in broad patches, there in winding courses, abruptly widening or narrowing, and so on?"

"If you accept of the view that the limestone was first made in great horizontal beds in the pure waters of a Lower Silurian sea; that the schist or slate was originally the sediment that in the following era was deposited over the limestone; that during the epoch of transition between the two conditions great sea-border marshes might have existed, receiving, here and there, like similar modern marshes, iron-bearing

ing solutions through the drainage of a bordering country, until ore-deposits were made, you may perhaps put together a theory that will account for the introduction and the peculiar irregular distribution of the ore in the limestone."

Daniels, Prof. Edward. Annual Report of the State Geologist of Wisconsin for 1857, 62 pp. *Madison*, 1858. Iron ores of Wisconsin occur:

"1st. In place as beds or veins in the rocks where they were originally formed or introduced."

"2d. Deposited from aqueous solutions in low ground, as bog ore or ochre."

Danton, D. Sur la Géologie et les Minerais de fer de l'Anjou. *Bull. Soc. Ind. Min. St. Etienne*, t. x, pp. 597-637, 1881.

Dathe, E. *Neues Jahrb. f. Mineral*, 1876, p. 226.

Daubrée, M. —. Observations sur l'original des filons titanifères des Alpes. *Ann. Mines*, vol. xvi, 1849, p. 129; *Géologie Experimental*, p. 37.

Daubrée, A. *Compt. rend.*, xxiv, 1543-1550. Abstract in *Canad. Nat.*, n. s. vol. vii, 1875, p. 52.

In reference to the masses of native iron discovered in Greenland by Nordenskiöld in 1870:

"The author is inclined to think that these masses of iron are not of meteoric origin, but that they have been formed from basaltic rocks and erupted from exceptionally great depths. These basaltic rocks frequently contain as much as 20 per cent. of ferric oxide, and it is not impossible that during their passage to the surface this oxide may have been partially reduced to the metallic state."

Daubrée, Prof. [Internal Structure of Native Iron from Ovivak.] *Compt. Rend.*, t. lxxxiv, p. 66, 1877.

Daubrée, A. [Report on Smith's Memoir on the Basalt with Native Iron of Greenland.] *Compt. Rend.*, t. lxxxvii, 1879.

Daubrée, C. [Iron-bearing Rocks of Greenland.] *Bull. Soc. Géol. France*, sér. 3, t. v, pp. 111-113, 1877.

Thinks it probable that the iron, like its basaltic matrix, is of terrestrial origin. (*Geol. Record*, 1879.)

Daubrée, Prof. [Recent Formation of Iron-pyrites in Thermal Springs and in Sea-water.] *Compt. Rend.*, t. lxxxi, pp. 854-859, 1875.

Davies, D. C. *Metalliferous Minerals and Mining*. London, Crosby, Lockwood & Co., 1880, pp. 274, 275.

Very erroneous, according to Wadsworth.

— Sketch of the Metalliferous Deposits of Flintshire and Denbighshire, Wales. *Eng. Min. Journ.*, vol. xxxvi, pp. 382-385, 397, 398. 1883.

Davis, O. W. Jr. The Iron Ores of Maine. *Jour. U.S. Assoc. Charcoal Iron Workers*, vol. 7, No. 2, p. 66, 1886.

"The measures in the vicinity of the Katahdin iron works are Silurian clay slates, which run like most of the rocks in this part of the State, slightly north-east by south-west. The regularity of the slates has been disturbed by a body of rock thrown up through which is a micaceous iron pyrites. The decomposition and oxidation of this pyrite has formed the deposits at Katahdin. For many years the furnace was run wholly upon ores which were simply the precipitates of oxide of iron held in solution by the waters of mineral springs that came up through the pyrites and deposited the iron on the sides of the mountain. The ore is all found on the sides and summit of an elevation that is from 200 to 400 feet above the level of the river. When the surface deposits became exhausted it was found that extensive deposits existed at various depths below the surface that were the product of oxidation of the ledge *in situ* occurring to the depth of 10 to 30 feet. These are sources of the present supply of the furnace, and appear to be inexhaustible."

Davis, Rev. —. Native Iron in Liberia, South Africa. *Annual of Scientific Discovery*, 1856, p. 304.

Davis, R. H. The Mineral Wealth of Harrogate. *Proc. Yorksh. Geol. Soc.* vol. viii, pp. 357-366, 1884.

Davy, L. P. [Geology of the Segré District (Maine et Loire), especially of the Ironstone Beds.] *Bull. Soc. Ind. Min. St. Etienne*, sér. 2, t. ix, pp. 537, 635, 1880.

Dawson, Geo. M. The Iron Ores of British Columbia. *Jour. U. S. Assoc. Charcoal Iron Workers*, vol. 8, No. 4, p. 233, 1889. Taken from *Mineral Wealth of British Columbia*.

Dawson, J. W. On the Geological Structure and Mineral Deposits of the Promontory of Maimansee, L. Sup. *Canad. Nat. and Geol.*, 1857; ii, 1-12.

———. *Can. Nat. n. s.*, vol. vii, p. 129.

———. On the Geological Relations of the Iron Ores of Nova Scotia. *Proc. Amer. Assoc.*, vol. xxii B., pp. 138-146, 1873.

Describes iron ores as occurring in the two forms of beds and veins. He mentions veins of hematite, limonite and magnetite, and thinks they are contact veins except where they occur in Triassic trap.

———. *Acadian Geology*, pp. 588, 589; 1878.

Considers the various iron ore deposits which he describes in Nova Scotia to exist as *veins*, filled by molten or sublimed material. He describes in detail the outcrops and enclosing rocks of a large *vein* in Londonderry, on the southern slope of the Cobequid Hills, concluding as follows:

"The geological history of this deposit embraces the following occurrences: 1st. The formation of a wide, irregular fissure along a great part of the length of the Cobequid mountains. 2nd. The filling of this fissure with a molten or softened, and partially even sublimed mass of ferruginous and calcareous matter, presenting, as I think, an evident illustration of the igneous formation of a vein of calcareous magnesian and ferruginous carbonates. 3d. The breaking up of the vein thus formed by cross-fractures and faults. 4th. The partial roasting of its contents by heat, so as to produce the red ores, which are obviously the result of the heating and oxidation of a part of the carbonate of iron, and this process may be seen on minutely examining the vein, to have extended itself from the walls of the smallest fissures. 5th. The action of heated waters passing through its crevices and depositing sulphate of barytes and brown hematite. 6th. The influence of the air and surface waters in changing large portions of the superficial contents of the vein into ochrey hydrous peroxide of iron. It is, however, to be observed that this deposit may be accounted for on the supposition that a bed of iron ore and carbonate of lime and magnesia, similar to those occurring elsewhere in the upper Silurian, had been so softened and altered by heat as to penetrate in vein-like forms the surrounding rocks. Sir W. E. Logan has shown that phenomena of this kind occur in the Laurentian regions of Canada.

Veins of iron ore, similar in character to those above described, occur in nearly every part of this metamorphic district; they are, however, of small magnitude, and I am not aware that they are in any place of workable dimensions. In many places extensive masses of shattered quartzite and slate are penetrated in every direction by slender veins of micaceous specular ore.

In addition to these veins of iron ore, conformable beds, as already mentioned, exist in the upper Silurian slates, more especially on the East River of Pictou, at the locality indicated on the map. At this place one bed appears to be forty feet thick, and much resembles that in the Devonian at Nictaux, but the ore is more silicious and contains only about forty per cent. of metal."

Dawson, S. J. Reports on the exploration of the Country between Lake Superior and the Red River Settlement, etc. *S. J. Dawson and H. Y. Hind*, Toronto, 1858, 1859.

Day, St. John V. The Iron and Steel Industries of Scotland. In Notices of Some of the Principal Manufactures of the West of Scotland. 8vo. *Glasgow*, pp. 60. 1876.

Deby, Julien. Report on the Progress of the Iron and Steel Industries in Foreign Countries. *Journ. Iron Steel Inst.*, pp. 213-302, pt. i, and pp. 1-243, pt. ii. 1877.

De Castro, Manuel Fernandez. On the Influence which a molecular movement due to electricity may have exerted in certain geological phenomena, namely, the metamorphism of rocks and the formation of metalliferous deposits. Extract from a pamphlet; Discursos leídos ante la Real Academia de Ciencias, etc., en la recepción pública del Excmo. Sr. Don Manuel Fernandez de Castro, Madrid, 1878.

"Electro-telluric actions may have played an important part in the formation of the grains of oxide of iron in the Tertiary; the oolitic iron-ore in the Jurassic deposits; the sphero-siderite of the Carboniferous formation and the geodic iron-ore of the modern formation."

Dechen, H. von. *Leonhard's Jahrbuch*, 1851, p. 210. Entirely excludes the igneous-fluid injection theory; adopts that of infiltrations from below.

———. Ironstone and Pyrites of the Zeche Schwelm. *Verh. nat. Ver. preuss. Rheinl. Jahrg.* xxxi, Sitz. pp. 108-113. 1874.

"**Deck,**" Dr. Report of the American Magnetic Iron Company, 1857.

In speaking of the Theall vein near Croton Falls, N. Y., says, (Iron Manfr's Guide, p. 407):

"In conclusion, I would note that in applying the term 'bed or deposit' to this ore, I allude to its present aspect as qualifying the expression; but when the walls are reached on either side, its characteristic features as a vein will fully develop themselves, for there is no doubt whatever that these iron accumulations are *true veins*, and are thus connected with larger masses below of an unknown width and depth."

Deicke, J. C. *Berg. u. Huttenm. Zeitung.* p. 339. 1853.

De La Beche, Henry T. Report on the Geology of North Cornwall, Devon and West Somerset, pp. xxii, 648, maps, etc., *London*, 1839.

On the subject of the filling of veins by electro-chemical action Mr. De La Beche says on p. 372;

"The whole of the evidence, both of successive coatings of different substances in veins where the fissures seem always to have retained the same width, and of the coatings and different modifications of the contained mineral substances in those veins which have suffered successive dislocations, goes to prove that chemical or electro-chemical conditions in the lodes have varied materially at different times, producing a corresponding variety in the arrangement and number of the various mineral substances contained in them, and causing aggregations of similar matter in some places and repulsion of different matter in others."

———. On the Formation of the Rocks of South Wales and Southwestern England. *Mem. Geol. Sur. Great Britain.* Vol. 1., 1846.

On page 185 is discussed the origin of clay ironstone: "Mr. Hunt (keeper of Mining Records in the Museum of Economic Geology) having instituted a series of experiments to illustrate the production of these clay or argillaceous ironstones, found that decomposing vegetable matter prevented the further oxidation of the proto-salts of iron, and converted the per-oxide into the protoxide of iron by taking a portion of its iron to form carbonic acid. Under the conditions necessary for the production of coal distributed among the associated sand, silt, and mud, the decomposition of vegetable matter would necessarily form carbonic acid among the products. This carbonic acid mixed with the water would spread with it over areas of different dimensions according to circumstances, forming salts and meeting with the protoxide of iron in solution, it would unite with the protoxide and form a carbonate of iron. The carbonate of iron in solution would mingle with any fine detritus which might be held in mechanical suspension in the same water, and hence when the conditions for its deposit arose, which would happen when the needful excess of carbonic acid was removed, the carbonate of iron would be thrown down mingled with the mud. Under such conditions it would resemble carbonate of iron mixed with mud, and both would alike form impure beds either of carbonate of iron or of lime, as the case may be, according as the matter deposited from solution exceeded that thrown down from mechanical suspension. Both would also form nodules, in the usual manner, occurring in planes amid the mud where the carbonates were insufficient to constitute continuous beds."

Delafield, Joseph. Notice of new Localities of simple minerals along the north coast of lake Superior, etc. *Ann. Lyc. Nat. Hist.*, 1824, i, 79-81.

Delesse, A. Mines de Fer des États-Unis. *Annales des Mines*, 1857, (5), xii, 805-841.

Delius, C. T. Abhandlung von den Ursprünge der Gebirge. *Leipzig*, 1770.

De Luc, J. A. Geological Travels. 3 vols. 1811. Mines of Cornwall, Devon and Somerset are described.

De Rance, C. E. On the Iron and Lead measures of Tynehead, Alston. *Rep. Brit. Assoc.* for 1882, p 531. 1883.

———. On the Occurrence of Manganese and Hæmatite at Nant Uchaf near Abergelle, Denbighshire, in Old Red Sandstone or Carboniferous Basement beds. *Coll. Guard*, vol. xliv, p. 895, 1882. *Trans. Manch. Geol. Soc.*, vol. xvii, pp. 47-56, 1883.

Derby, Orville A. *Am. Jour. Sci.* (iii) xxiii, p. 373, May, 1882.

Descostils, M. Collet. Chemical Observations upon Spathic Iron. Read at the class of the Sciences in the French National Institute, Jan. 6, 1806. *Jour. des Mines*, vol. xviii, 1806. *Annales de Chimie*, lxxxiv, 188, 1812.

Devereux, W. B. Notes on Iron-ore Deposits in Pitkin County, Colorado. *Trans. Amer. Inst. Min. Eng.*, vol. xii, pp. 638-641, 1884.

Dewey, Prof. Chester. Ores of Iron and Manganese in Bennington Vt. *Silliman's Journal*, vol. v, p. 250, 1822.

———. A Sketch of the Geology and Mineralogy of the western part of Massachusetts. *Silliman's Journal*, vol. viii, 1824, p. 30.

Dewey, F. P. Some Canadian Iron-ores. *Trans. Amer. Inst. Min. Eng.*

vol. xii, pp. 192-204, 1884. *Jour. U. S. Assoc. Charcoal Iron Workers*, vol. v, No. 2, p. 67, 1884.

———. The Rich-Hill Iron Ores. *Trans. Amer. Inst. Min. Eng.* vol. x, pp. 77-80, 1882.

Dieulafait, L. *Revue Universelle des Mines*, vol. vii, 1880.

———. L'origine et la Formation des Minerais Métallifères. *Rev. Sci. t.* xxxi, pp. 609-618, 1883.

D'Inwilliers, E. V., and Lesley, J. P. Report on the Cornwall Iron Ore Mines. See **Lesley, J. P.** *Trans. Am. Inst. Min. Eng.* vol. xiv, p. 873, 1885.

D'Inwilliers, E. V. The Magnetic Iron Ores. *Rep. Prog. Penn. Geol. Survey.* D 3, vol. ii, pp. 237-352, 1883.

• "The magnetic ore beds of the South Mountains are regularly interstratified with the gneiss beds, and are evidently original sediments of limited extent, lens-shaped, swelling at the center, and tapering to an edge, both sidewise and downwards."

———. Iron industry and iron ores of Berks Co., Pa. *Second Geol. Sur. Penn., D 3, Part 1.* 1883. Harrisburg.

———. and **A. S. McCreath.** Comparison of some Southern Cokes and Iron Ores. *Trans. Am. Inst. Min. Eng.* vol. xv, p. 734, 1887.

Disturnell, John. The Great Lakes or Inland Seas of America. *New York*, 1863, 192 pp. and map.

Divers, E. On the Chrome Iron Ore of Japan. *Chem. News*, vol. xlv, p. 217; and *Rep. Brit. Assoc.*, for 1881, pp. 587-589. 1882.

Dobrynkin, N. [Mineral wealth of the district of Mourom.] *Gazette du gouv. de Wladimir*, Nos. 1-8, 1887.

Dolinsky, A., Chimanovsky, M. and Jassinsky, B. [Lignite and iron ore in the provinces of Podolie and Wolynie.] *Gazette des mines de la Russie meridionale*, No. 140-141, pp. 1887-1894. 1886.

Dolinsky, L. [Statistics for 1885 and 1886 of the Mining Region of the Southwest (of Russia).] *Journ. d. mines russes.* No. 12, pp. 485-501, 1887.

Donayre, F. M. [Geology, &c., of the S. E. of Almeria.] *Bol. Com. Map Geol. Espan.* t. iv, p. 385. 1877.

Dove, George, Jr. The Frodingham Iron Field, North Lincolnshire. *Journ. Iron Steel Inst.*, pp. 318-341, 1876.

Drown, J. M., and Skinner, P. W. The Analysis of Iron Ores Containing both Phosphoric and Titanic Acids. *Trans. Am. Inst. Min. Eng.*, vol. x, pp. 137-144. *Am. Chem. Journ.*, vol. iv, pp. 1-7, 1882.

Dufrenoy, M. Memoire sur la Position des Mines de Fer de la Partie orientale des Pyrénées, 1834. In this memoir

"Mr. Dufrenoy has recently shown that the mines of Hematite and Spathic iron in the Eastern Pyrenees, which occur in limestones of three ages, referrible severally to the Transition Series, to the Lias and to the Chalk, are all situated in parts where these Limestones are in near contact with the Granite; and he considers that they have all most probably been filled by the sublimation of mineral matter into cavities of the limestones, at, or soon after the time of the elevation of the Granite of this part of the Pyrenees." Buckland's *Geology and Mineralogy*, Bridgewater Treatise, vol. i, p. 508, 1858.

Du Noyer. Geology of Island Magee. *Nat. Hist. and Phil. Soc.*, Belfast, Nov. 1862.

Tried to demonstrate that the iron ore in the basalt of the Island Magee is "as true an aqueous conglomerate as if it had been found in the heart of the Old Red Sandstone."

Durocher, —. *Compt. rendu*, vol. xxviii, p. 607; vol. xiii, p. 850, 1849. Considered lodes to be formed by infiltrations, sublimations and igneous-fluid injections.

Eames, Henry H. Geological Reconnoissance of the Northern, Middle and other Counties of Minnesota. St. Paul, 1866, 58 pp.

———. Report of the State Geologist, on the Metalliferous Region Bordering on Lake Superior. St. Paul, 1866, 23 pp.

Eaton, Amos. An Index to the Geology of the Northern States. Boston, 1818.

"To counterbalance the lightness of the exterior crust, the interior of the earth must consist principally or wholly, of metallic or other very heavy substances, agreeable to our theory of successive deposits. It probably consists of several concentric layers of metals, of different specific gravities, arranged like the coats of our onion."

Egleston, Thomas. Boracic Acid in Lake Superior Iron Ores. *Trans. Am. Inst. Min. Eng.*, 1876, v, 131, 132.

Ehrenberg, —. Proceedings of the Royal Academy of Science, Berlin, 1844, 1845. Abstract of his papers in *Quart. Journ. Geol. Soc. Lond.*, Aug. 1846. *Vid.* also Taylor's Scientific Memoirs, vol. i, pt. iii, p. 402.

Ells, R. W. Iron Ore Deposits of Carleton County, New Brunswick, Geological Survey of Canada. *Report of Progress for 1874-5*, pp. 97-104, map, 1876. Describes certain red hematite deposits in the Cambro-Silurian slates of Carleton County, N. B.

Emmons, Dr. Ebenezer. Fourth Annual Report of the Survey of the Second Geological District of New York. 1840. p. 276. *Assembly Docs*, No. 50.

———. Natural History of New York, Part IV. Geology, Pt. ii, 1842. p. 97. "*Origin of the Magnetic and Specular Oxides of Iron.* I have had occasion so frequently to refer to igneous action, in my remarks upon unstratified and subordinate rocks, that I have already anticipated the views which I am about to present of these two oxides. It will be seen from the structure of the diagram, and from the general bearing of the facts, that such an origin is by far the most probable, though there are many geologists who maintain the theory of electro-magnetic agency; and it must be confessed that it possesses many plausible points, and a few facts which lend it some support. Still, as regards its establishment, it appears from the researches of Faraday, that we should be obliged to sustain it on the assumption that the materials must have been in a liquid state at the time of their formation; and as the principle of electro-magnetism has no power to act upon a substance, so as to transfer it from one point to another, if it is in a solid or aeriform state. Electro-magnetism, though it decomposes water, is unable to act upon ice, or to decompose any other substance when solid; this at least is the case in the experimental researches of the most eminent philosophers of the day, in relation to the decomposing and transferring power of this agent.

"The igneous origin of both oxides rests partly, as already stated, upon the establishment of the plutonic character of the rocks associated with them, and partly upon the mode of their occurrence in those masses. It is true, that the specular oxide appears among the lower layers of a sedimentary rock; but a careful inspection will satisfy most observers that it appears here as an intrusive rock, and that it has been forced into this position subsequent to the deposition of this sandstone; the evidence of which appears in the facts which have been stated in the preceding pages, viz: its fractured and upraised condition. And it is not at all remarkable that a porous sandstone should have been penetrated by this material, so as to appear somewhat homogeneous, when we consider the forces which must have acted previous to, and during its upheaval.

"I have noticed also, and it is a fact which has the same bearing as the others already stated, that some portions of the rock adjacent to the ore are porous, or somewhat vesicular; the pores are, however, quite small, but still they are quite characteristic, and are clearly different from that kind of porosity which arises from decomposition; they appear, in a word, like those in the sandstone of Connecticut river, in the vicinity of the greenstone trap. Of the origin, then, of the oxides of iron, there are a variety of facts of the same character, which, when observed in other rocks have been considered demonstrative of an igneous origin; if, then, we are not in error in relation to principles already conceived, we can scarcely refuse to apply them to the question of the origin of the ores of iron."

———. Topography, Geology and Mineral Resources of the State of New York. Published in a Gazetteer of the State of New York. *Albany*, 1842.

———. American Geology, Albany. 1855. pp. 139-155.

———. Geology of North Carolina, 1856, p. 84.

In that State "the oxides of iron occur only in veins excepting where the mass has undergone certain changes. The mode in which ferruginous veins have been filled is clearly that which is assigned to trap or granite. Iron, however, in combination with chlorine is volatile, and is vaporized and finally deposited in the condition of a peroxide or specular oxide."

Emmons, S. F. *Trans. Am. Inst. Min. Eng.*, vol. III, pp. 419-420. 1875.

"From the decomposition and oxidation of these various minerals, whether sulphurets or carbonates, hydrous peroxides will result, and hence we should expect to find them whenever these decayed rocks have escaped erosion."

———. Genesis of Certain Ore-Deposits. *Trans. Am. Inst. Min. Eng.*, xv, p. 137. 1887.

———. Structural Relations of Ore-Deposits. *Trans. Am. Inst. Min. Eng.* Boston meeting, 1888, pp. 36.

Eschwege, —v. Beiträge zur Gebirgskunde Brasiliens, 1832, p. 141; Pluto Brasiliensis, 1838, p. 225.

Fabre, G. [Siderolitic Deposits of Lozère.] *Bull. Soc. Géol. France*, 3 sér. t. iii, pp. 583-591. 1876.

"The Jurassic limestones are cut through and pierced by many veins and pipes of "eruptive" clays and granitic sands. Limonite, associated generally with oxide of manganese, occurs in these veins, the sides of which are corroded. These deposits occur also occasionally in sheets at the mouths of the veins, whence the belief that they have been ejected. The principal direction of the veins and pipes is N. N. W. All these accumulations are referred to geyserian action towards the close of the Eocene period."

Fahlerantz, A. E. [Iron-ore District at Dannemora, Sweden.] *Bihang. k. Svenska Vet.-Akad. Handl.* Bd. 4, No. 2, pp. 1-15, 6 plates. 1877.

Faller, G. *Berg- u. Hüttenm., Jahrb. d. k. k. östr. Bergacadem.* 1867. Bd. xvii, p. 132.

Feistmantel, K. [The Ironstone of Subdivision D, of the Bohemian Silurian.] *Sitz. k. böhm. Ges. Wiss.* May, 1878.

Felkner, J. [Coal and Iron in Russia.] Pp. 174, 1 map. St. Petersburg, 1874.

Festenberg-Packisch, H. v. Der metallische Bergbau Niederschlesiens etc., 8vo, Vienna. Pp. 117; map. 1880-81.

Firket, A. [Manganese-iron Bed of Moët-Fontaine.] *Ann. Soc. Géol. Belg.* t. v, pp. 33-41. 1878.

"The bed at a depth from the surface, consists of carbonate of iron and carbonate of manganese in about equal parts; at the outcrop it shows two divisions, one rich in oxides of iron and manganese, the other of schist and quartz-slate, passing into grits and poor in metals. The oxides are the result of atmospheric alteration. The bed is not a vein, but of the same age as the U. Silurian rocks with which it is associated." *Geol. Record*, 1878.

———. [Metalliferous deposits of the Landenne Mine, and the Silurian Fault of Champ d'Oiseaux.] *Bull. Ac. Roy. Belg.* sér. 2, t. 45, pp. 618-645, folding plate, 1878.

"1. On the Silurian Fault and lodes of champ d'Oiseaux (Landenne sur Meuse). 2. Structure and lie of the Hæmatite beds. 3. Epigenic change of oolitic hæmatite into siderite in contact with a vein of pyrites. 4. On the relation between this phenomenon and the metalliferous infilling of the lodes of the Landenne mine. Concludes that the water to which he attributes the metalliferous deposit was charged with carbonic acid. To the action of the last is due the enlargement of the fissures in the Carboniferous age, (where the lodes are richest). The thinness of the vein in the shales is referred to the weak action of acid on the rocks."

Fleming, H. S. General description of the Ores used in the Chattanooga District. *Trans. Am. Inst. Min. Eng.*, vol. xv, p. 757. 1887.

Flight, Walter. History of Meteorites. *Geol. Mag.*, vol. ii, Decade ii, 1875, pp. 115-123; 152-157.

"Meteoric irons found August, 1870.....Ovifak.....Island of Disco, Greenland," are discussed.

———. Supplement to a Chapter in the History of Meteorites. *Geol. Mag.* vol. ix, Dec. ii, 1882.

The Ovifak iron is discussed on pp. 58, 59 of this volume. This author here concedes the terrestrial origin of this iron. He says that:

"In the Greenland beds layers of lignite are found associated with the basalt, and this may have furnished the material which has reduced the iron to the metallic state." p. 59.

Foerste, Aug. F. On the Clinton Oolitic Iron Ores. *Am. Jour. Sci.*, iii, xli, Jan. 1891, p. 28.

"It is evident that the origin of the oolitic structure is not due to a concretionary segregation of iron particles, but finds its explanation in the gradual replacement of the lime of the fragmental fossil bryozoans, particle after particle, by the iron ore."

Foote, R. B. The Geological Features of the South Mahratta Country and Adjacent Districts. *Mem. Geol. Surv. Ind.*, vol. xii, pp. 268, 1876.

Forrest, R. J. On the Bilbao Iron Ore District. *Trans. N. Engl. Inst. Eng.*, vol. xxxiii, pp. 213-234, 1884.

Foster J. W., and J. D. Whitnev. Report on the Geology of the Lake Superior Land District. Pt. ii, pp. 50-69, 1851.

Might be quoted quite extensively. Their idea is summarized in the following paragraph.

"On the whole we are disposed to regard the specular and magnetic oxide of iron as a purely igneous product, in some instances poured out, but in others sublimed, from the interior of the earth. The supposition entertained by some, that it may be a secondary product, resulting from the decomposition of the pyritous ores, or from the metamorphism of bog-iron, is inadequate to account for the accumulation of such mountain masses, or to explain its relations to the associated rocks."

———. *Amer. Journ. Sci.*, (ii) vol. xvii, pp. 11-38, 1854, vol xxii, pp. 305-314.

They here state that after this series of igneous and aqueous ore beds was laid down:

"The whole series of beds, slaty, quartzose, ferruginous and trappean, were elevated and in all probability, folded, perhaps at the epoch of the elevation of the granite ranges on the north and south of the ferriferous belt of the Azoic system."

———. Report on the Iron District of Lake Superior. Senate Docs., 2d Sess. 31st Cong., 1850-51, ii, No. 2, 147-152.

Foster, J. W., and J. P. Kimball. Geology and Metallurgy of the Iron Ores of Lake Superior. *New York*, 1865, 97 pp. with maps. Report to the Board of Directors of the Iron Cliffs Company.

Foster, J. W. Report on the Iron Smelting Coals of S. Indiana. *Pittsburg, Pa.*, 1871.

———. Senate Documents, 1st Session, 30th Cong., 1847-8; ii, Doc. 2, pp. 773-785, 1849.

Gives a description of the iron region as studied by him in 1848. He regards the iron ores as of sedimentary deposition.

"These beds, so far as I have observed, present a marked similarity in mineralogical characters and derive their origin from common causes and those were aqueous. The jointed structure and waved stratification of some of the beds prove that igneous causes have operated, since their deposit, to modify and change their character. (p. 776.) Here they certainly bear upon their surfaces strong marks of their mechanical origin. They are regularly stratified and often contain thin seams of siliceous grains so that a specimen on its cross fracture resembles ribbon-jasper. The lines of stratification can readily be distinguished from those of lamination. Like the slates they are often found contorted and wrinkled, and the same facts could be adduced in both cases to prove their common origin." (p. 779.)

———. Ancient Mining by the Mound Builders, in the "Pre-historic Races of the United States." *Chicago*, 1873; pp. 361-374.

Foster, Dr. C. Le Neve. Notes on Haytor Iron Mine. *Quart. Jour. Geol. Soc.*, vol. xxxi, pp. 628-630, 1875.

"Magnetite ore occurs in four beds interstratified with altered shales and sandstones of Carboniferous age. Above one of the beds of magnetite is a thin vein of granite, apparently interstratified, but which is proved upon examination to break across the rocks. The iron-ore perhaps originated in the form of beds like the Cleveland ore and has been altered into magnetite, the neighboring rocks having become extremely siliceified, but possibly the apparently stratified magnetite may have been formed by ferruginous emanations."

———. Notes on the Perseberg Iron Mines, Sweden. *Brit. Assoc. Adv. Sci. Trans. Sections*, p. 60.

Magnetic "deposits were considered to have existed originally in the form of beds in sedimentary rocks, like the Cleveland Iron ore for instance, and to have been since metamorphosed; the fact that the ore is accompanied by hornblende, garnet, &c., is explained by the supposition that it was the ore that furnished the iron which enters into the composition of these minerals."

Fournet, J. Études sur les Depots Métallifères. 3 folding plates, 8vo. *Paris*. 1834. Published in the third volume of *D'Aubisson's Traité de Géologie*.

Fox, Robert Were. *Annals of Philosophy*, vol. iv, p. 447. 1822.

"Electrical action might contribute to produce the extraordinary aggregation and

position of homogeneous minerals in veins." He also considered that this action is still going on in veins.

———. *Some Remarks on Mineral Veins. Phil. Mag. and Annals of Philosophy*, n. s., vol. vi., p. 17. 1829. Rep. of the Roy. Cornwall Polytechnic Soc. for 1836.

———. *Philos. Trans.* 1830, p. 399; *Trans. Roy. Soc. Geol. Cornwall*, 1832, p. 31; 1840, v, p. 445; *Phil. Mag.* 1836, ix, p. 387; 1839, xiv, p. 145; *Brit. Assoc. Adv. Sci.* 1837, 133, 137; *Leonhard's Jahrbuch*, 1840, p. 114.

He believed that electricity has exerted a great influence in the arrangement of minerals in lodes, and that fissures are the consequences of electrical currents in particular directions, and on this account they were originally formed in an E. W. direction.

———. Account of some experiments on the electricity of the copper vein in Huel Jewel Mine. *Rep. Brit. Assoc.* 1834, p. 572.

———. Note on the Electric Relations of certain metals and metalliferous minerals. *Phil. Trans.* I, 39. 1835.

———. Report of the Cornwall Polytechnic Society for 1836. *Falmouth*, 1837, p. 115.

"When a solution of sulphate of iron was substituted for the sulphate of copper in the cell containing the copper ore the latter appeared at first to have on its surface a deposition of iron, and this, becoming oxidated, in time formed an incrustation which resembled *gossan*." * * "Sulphurets of metals might have been thrown down by sulphureted hydrogen, generated by the action of electricity on yellow copper ore."

———. Some experiments on subterranean electricity, made at Penance Mine, near Falmouth. *Phil. Mag.* (3), xxiii, pp. 457, 491, 1843.

Fraser, Robert. General View of the County of Cornwall. *Agricultural Reports*, vols. i, ii. 1794.

Frazer, Dr. Persifor. *Report C, 2nd Geol. Surv. Penn.*, p. 134, 1874.

With reference to the magnetites, hematites and limonites connected with limestone in York and Adams counties, he states:

"It is likely that the origin of the ore is to be sought partly in segregation and partly from alteration of iron minerals in situ. Of the former class are those glassy botryoidal and stalactitic ores (Butcher's, Moser's banks, etc.,) whose pyramidal needles clearly show the position they held while in the course of formation.

But other cases occur in which masses of ore of irregular shape and limited extent lie between the beds of the slates and not only partake of the general dips of the latter, but share with them the most intricate and sudden convolutions."

Referring to the magnetic and specular ores which occur in the Mesozoic sandstone in the northern parts of York and Adams counties, he says (l. c. p. 137.):

"The source of this iron supply has been ascribed to the minute crystals of pyrite which undoubtedly permeate some horizons of the great calcareous deposit, but their number and the porousness of the limestone as observed in connection with the ore, seem to bear no relation to the latter. It seems much more probable that the supply of iron was obtained from the pyrite crystals of the lower slates. Even the slates which are not so situated as to permit the percolation of water through them, exhibit a porous structure, the pores being filled with brown ochreous limonite; and this occurs to an unknown depth, and the slates seem to merge by imperceptible degrees in a direction normal to the plane of bedding, first into completely metasomatized pseudomorphs of limonite after pyrite (but still retaining the form of the latter); then the same with a kernel of pyrite, then the pyrite itself, first with a shell and then with a mere stain of ferric hydrate; and finally the same slates are revealed porphyritic from the pyrite and not at all decomposed.

"As to the origin of the iron in these limonite beds, is the iron derived from the percolation and solution of the pyrite disseminated through the more recent limestone beds; or does it come from the decomposed pyrite in the less recent slates? If the former hypothesis be the true one, we should expect to see an absence of limestone in the vicinity of the large deposits, for granting for the moment that the limestone contain enough pyrites to account for the entire deposit (a fact which at least admits of some question), a percolation of water sufficient to oxidize the sulphur of these pyrite crystals and carry away enough iron to produce the beds, would entirely honey-comb and finally, both by solution and attrition, dissipate the pyritiferous belts of limestone. But in and near some of the largest limonite beds we find the limestone scarcely weathered, and in a few cases, if any, it is rendered ferruginous or even stained to any great degree by chalybeate waters. Indeed the absence of the familiar iron stain from the calcareous member of this formation is so marked, that this point of difference from the adjacent members of the series cannot fail to arrest attention. * * * * It is objected in short to the hypothesis which would derive the limonite beds from the disseminated pyrite in the overlying limestone; 1st. That the position of the beds does not seem to effect the extent of the deposit, there is no appearance of wasting in the limestone commensurate with the effect produced, and not even the staining from

chalybeate waters which must have accompanied such a genesis. 2d. Very similar deposits are found in horizons far below the limestone, as at Hofackers, the Hanover Junction railroad range, etc."

He then goes on to show how the limonite may have been derived from the pyrite in the underlying slates, and quotes Rogers, Vol. 1, p. 183. *Geol. Penn.* in reference to the older limonite deposits of Lancaster county:

"An interesting inquiry is here suggested as to what can have been the geological atmospheric condition which produced the remarkable percolation which carried down so large an amount of ore out of these ferruginous beds. Was it tepid rain charged with carbonic acid in an early Palaeozoic period? Or could it have been a long filtration of surface waters such as now soak the earth? Or are we to surmise an action of internal steam issuing upwards through crevices in a period of crust movement and disturbance? I am inclined to the first conjecture."

He also quotes Hunt's Essay on metalliferous deposits. (xii. *Chem. and Geol. Essays*, Boston, 1875, p. 229):

"The question has been asked me—Where are the evidences of the organic material which was required to produce the vast beds of iron ore found in the ancient crystalline rocks? I answer that the organic matter was, in most cases, entirely consumed in producing these great results, and that it was the large proportion of iron diffused in the soils and waters of those early times which not only rendered possible the accumulation of such great beds of ore, but oxidized and destroyed the organic matter which in later ages appears in coals, lignites, pyro-schists and bitumens. Some of the carbon * * is, however, still preserved in the form of graphite."

Later Dr. Frazer says:

"With reference to the Ferric Sulphide or pyrite, the same author ascribes its formation to the deoxidizing agency of decaying organic matters out of contact with air on soluble sulphates of lime and magnesia, giving rise, if carbonic acid be present, to Hydrogen Sulphide, etc. * * *"

"It seems at least a possible explanation for this more prominent determination of limonite along the edge of the limestone, that by the oxidation of the pyrites of the slates an equivalent of sulphuric acid in addition to that necessary to form Ferric Sulphate has been produced. That this molecule of free sulphuric acid in its passage over the mica and chlorite slates has dissolved out part of their alkalies, especially soda. That this solution of sodium sulphate has mingled in the clay beds below with the solution of calcium bicarbonate produced by the drainage of rain waters over the limestone beds, giving rise to sodium bicarbonate and calcium sulphate. That this sodium bicarbonate reacting on the Ferrous Sulphate has precipitated Hydro-Ferrous Carbonate which has been by oxidation rapidly converted to Ferric Hydrate, while the Ferric Sulphate has been immediately thrown down as hydrous oxide."

"The theory of the alteration in situ of various iron minerals resulting in the formation of many of these limonites, advanced by C. U. Shepard many years ago, and ably discussed and accepted by Dr. T. S. Hunt, cannot be disregarded in seeking the causes which produced these limonites." (l. c. p. 143.)

— Titanic Iron. *Proc. Am. Phil. Soc.*, 1875, xiv, p. 430.

—, Origin of the Lower Silurian Limonites of York and Adams Counties, Pennsylvania, *Proc. Amer. Phil. Soc.*, March, 1875, pp. 364-370, 433. Abstract in *Amer. Journ.* ser. 3, vol. ix, p. 471.

"Attributes the origin of the ore to the presence of the pyrites in the slates."

—, A Study of the Specular and Magnetic Iron Ores of the New Red Sandstone in York County, Pennsylvania. *Trans. Am. Inst. Min. Eng.*, vol. v., 1876-77, pp. 132-143.

—, Some Mesozoic Ores. *Proc. Am. Phil. Soc.*, 1877, xvi, 651.

—, Remarks on Prof. Prime's paper. *Proc. Amer. Phil. Soc.*, vol. xvii, No. 100, pp. 255-258, 1877.

"The hematites are probably due to oxidization of iron-pyrites, and aggregation of the oxide at the lowest point to which water percolated."

—, Experiments to illustrate the formation of limonite. *Proc. Am. Phil. Soc.*, 1878, xvii, p. 289.

—, Missing Ores of Iron. *Trans. Amer. Inst. Min. Eng.*, vol. vi, pp. 531-542, 1879; *Metall. Rev.* I, No. 5, 1878.

—, Discussion of Blandy's Paper on the Lake Superior Rocks in Pennsylvania. *Trans. Am. Inst. Min. Eng.*, vol. vii, 1880, p. 336.

—, Ores of the Middle James River. *Trans. Am. Inst. Min. Eng.* Virginia Meeting 1881.

—, *Penn. Geol. Sur. Rep. Prog. C 4*, p. 238, 1883.

Speaking of the Warwick Iron Mine says:

"This extensive and interesting body of iron ore, situated just S. E. of St. Mary's Episcopal church, is in reality not a genuine lode or igneous intrusive vein, though the ore derives some of its characters from intrusive igneous action: but it is a bed or deposit at the base or very near the base of the middle secondary red sandstone, which

here laps on the gneiss. * * * * * This is intermediate in its physical character and aspect between the true brown hæmatite and the magnetic oxide of iron. As on the view of its having been originally a hematite, but subsequently altered by igneous action, we might naturally anticipate those portions of it which have undergone the highest degree of metamorphic influence are of a light grey color, quite crystalline, and partially endowed with magnetic force, whereas the less altered parts are nearly in the condition of a compact, closely cemented hæmatite."

In reference to Crossley's iron ore pits (l. c. p. 242) he says:

"Sufficient indications prevail, and enough information is accessible in the neighborhood and through persons at one time commercially interested in the success of the mines, to satisfy me that these several parts all pertain to an irregular lode or a chain of closely connected lodes of igneously derived magnetic oxide of iron. This vein occurs between walls of gneiss rock in a low ridge just E. of the N. branch of French creek."

Speaking of the mines of West Caln county (l. c. p. 260) Dr. Frazer advances briefly other theories for the formation of iron ore as follows:

"In general these mines resemble those so often mentioned and described in Report C (York County). The iron ore in them seems to have been derived from two sources, a primary and a secondary. The first is the alteration in place of strings, pockets and beds of pyrites, and other iron compounds, producing a corresponding mass of iron more or less hydrated. The second is intimately connected with the disintegration of the rocks themselves, and depends upon it, and is in fact a deposit of oxides of iron among the impermeable clays, caused by the disintegration of the feldspars from its solution."

———. Silver and Iron Mines of Nuevo Leon and Coahuila. Read before *Am. Inst. Min. Eng.* Feb., 1884, p. 20. Speaking of some hematite and magnetite at La Palma mine near Monclova in Coahuila, Dr. Frazer says:

"The strike of the limestone and of the ore nearly agree, and the latter has been probably deposited in one of the joints or cleavage planes of the former, though it is possible that the spur itself may be anticlinal, and the iron ore deposit a true bed-vein. In either case there is the clearest evidence that the iron ore is an alteration product of the pyrite, but so complete has been the alteration that a few inches above the line of demarcation between the sulphide and the oxide of iron, hardly a trace of the sulphur remains."

Freiesleben, —. Bemerk. über d. Harz, 1795, p. 259. Iron ore deposits of the Harz are described.

Frontzkewitch, —. [Deposits of Oil and Iron ore at Olkhovatka.] *Gazette des mines de la Russie méridionale*. No. 133. 1886.

Frus, T. [The Iron and Copper pyrites Deposits at Röros, Norway.] *Nyt. Mag. Nat.* Bd. 22, p. 321. 1877.

"An account of the probable connection between the different mines in the district, and a discussion whether the ores are deposited as layers or as veins."

Fuchs, T. Sur les gites de fer et de cuivre gris de la petite Kabylie. *Compt. Rend. Assoc. France*, p. 567. 1881.

Fuchs, W. Beiträge zur Lehre von den Erzlagertstätten. *Vienna*, 1856.

Gaetschmann, Moritz F. Die Auf- und Untersuchung von Lagerstätten nutzbarer Mineralien als 1. Theil der Vollständigen Anleitung zur Bergbaukunst. *Freiburg*, 1856. *Leipzig* 1866.

Gage, J. R. *Trans. St. Louis Acad. Sci.*, vol. iii, No. 1, 1873, pp. 181-192.

Concludes that the Pilot Knob iron ore beds were formed by replacement, the iron being derived by lateral secretion.

Gallois, M. de. Sur les Minerais de Fer des Houillères, ou Fer Carbonaté Lithoïde. *Annales des Mines*. 1818. iii, 517. A valuable and learned memoir for the age when it was written.

Garnier, Jules. [Iron near Brest.] *Rev. Géol.* t. xi, pp. 76-77.

———. [Iron Ores of Brittany.] *Rev. Géol.* t. xii, pp. 91, 92. 1875.

Geikie, Archibald. Text-Book of Geology. 1882. pp. 67, 68. *et seq.*

"In the crystallized form the mineral (hematite) occurs in veins as well as lining cavities and fissures of rocks. The fibrous and more common form (which often has portions of its mass passing into the crystallized condition), lies likewise in strings or veins; also in cavities, which, when of large size, have given opportunity for the deposition of great masses of hematite, as in cavernous limestones (Westmoreland). It occurs with other ores and minerals as an abundant component of mineral veins, likewise in beds interstratified with sedimentary or schistose rocks. * * * It appears abundantly as a product of sublimation in the clefts of volcanic cones and lava streams. In veins and beds among rocks it is probably in most cases a deposition from water, resulting from the alteration of some previous soluble combination of the metal, frequently the oxidation of the carbonate. It is found pseudomorphous after

ferrous carbonate, and this has probably been the origin of beds of red ochre intercalated among stratified rocks." * * * Magnetite may "result from either aqueous or igneous action. It has likewise been observed with hematite, &c., as a product of sublimation at volcanic foci where chlorides of the metals in presence of steam are resolved into hydro-chloric acid and anhydrous oxides."

"Ironstone.—Under this general term are included a number of iron ores in which the peroxide, protoxide and carbonate enter in various mixtures with clay and other impurities. They have generally been deposited as chemical precipitates on the bottom of lakes under marshy ground or within fissures and cavities of rocks." (p. 115.)

"The existence of beds of iron ore among geological formations affords strong presumption of the existence of contemporaneous organic life by which the iron was dissolved and precipitated." (l. c. p. 463.)

"Still further evidence in favor of organized existence during Archæan time in the North American area has been adduced from the remarkably thick and abundant masses of iron ore associated with the Laurentian rocks of Canada and the United States. Dr. Sterry Hunt has called attention to these ores as proving the precipitation of iron by decomposing vegetation during the Laurentian period on a more gigantic scale than at any subsequent geological epoch. (Geol. Can. 1863, p. 573.) Some of the beds of magnetic iron range up to 200 feet in thickness. Large masses also of hematite and titaniferous iron, as well as of iron sulphides occur in the Canadian Archæan series." (p. 639, loc. cit.)

Genth, F. A. Investigation of Iron Ores and Limestones from Messrs. Lyon, Short & Co.'s Iron Ore Banks on Spruce Creek, Half-Moon Run and Warrior's Mark Run, in Centre, Blair and Huntingdon counties, Pa. *Proc. Amer. Phil. Soc.* vol. xiv, No. 92, pp. 84-99. 1874.

Gerhard, C. A. Geschichte des Mineral-Reichs. Berlin. 1781.

Gesell, Sándor. [Geology of the Marmaros Iron-ore]. *Földt. Közl.*, vol. iv. 1874.

———. [Geological Notes on the Marmaros Ironstone Mining District.] *Math. Természet. Közlem.* Kot. xii, pp. 189-216, 2 maps, 1876.

Deals with Metamorphic, Triassic, Liassic, Cretaceous, Eocene, Recent and Igneous rocks.

Gesner, William. On the Coal and Iron Resources of Alabama. *Proc. Ac. Nat. Sci. Phila.* p. 163. 1876.

Giesler, E. [The Oolitic Iron-ores of German Lorraine.] *Zeitsch. Berg-Hütt. Salinenw.* vol. xxiii, pt. 1, pp. 9-41. Abstract in *Proc. Inst. Civ. Eng.*, vol. xlii, p. 358. 1875.

Gill, W. The Iron-ore District of Bilbao. *Lond. Iron Trades Exchange*, vol. xxx, p. 604; and *Journ. Iron and Steel Inst.*, p. 63. 1882.

Gilpin, E. The Iron Ores of Nova Scotia. *Trans. N. Engl. Inst. Eng.*, vol. xxvi, pp. 71-89. 1877. *Trans. Amer. Inst. Min. Eng.* vol. xiv, p. 54, 1885.

———. Notes on Specimens of Iron Ores, etc., collected in Pictou for the Philadelphia Exposition. *Trans. Nov. Scot. Inst.*, vol. iv, p. 137. 1877.

Gjers, John. A Short Historical Sketch of the Rise and Progress of the Cleveland Iron Trade. *Trans. Chesterfield Inst. Eng.*, vol. iii, p. 63, pl. xxviii, (section). 1875.

Gladky, P. [Chemico-geological notes on the Médnoroudiansk and and Wissokaia Gora deposits near Nijny-Tagil.] *Jour. des mines russes.* No. 1. pp. 96-123. 1888.

Glinzer, Dr. E. Das Eisen, seine Gewinnung und Verwendung. Pp. vii, 106, 8vo. Hamburg. 1876.

Goenaga, Ignacio de. Criaderos de hierro de Vizcaya. *Revista Minera.* ser. C, vol. i, pp. 296-299, 311-314, 328, 329, 339-341, 355-358. 1883.

Goss, W. H. Cloud Hill, On the Origin of the Millstone Grit, Clay and Ironstone, etc. [Read before N. Staff. Field Club, 20 May, 1881]. 8vo, London and Derby, 1881.

Gould, Charles. Report on the Iron Ores of Londonderry in Nova Scotia, the property of the Steel Company of Canada, Limited. Pp. 52, 8vo, London. 1875.

Grand, Albert. The Coal Basin of the Asturias. *Coll. Guard.*, vol. xxxii,

pp. 13, 51, 91, 134, 171, 211, 251, 291, 331, 371. Translated from the Proceedings of the French Society of Civil Engineers. (1876).

Refers particularly to the Iron-ores of the District.

Gray, A. B. Report on Mineral Lands of Lake Superior. Executive Docs., 1st Sess. 29th Cong. 1845-46, vii, No. 211, 23 pp. with map.

Grimm, Johann. *Berg- u. Hüttenm. Jahrb. d. k. k. östr. Bergacad.* 1867, vol. 16, p. 306; 1870, p. 170.

Grimm, Johann. Die Lagerstätten der nutzbaren Mineralien. *Pribram, Bohemia.* 1869. *Prag.* 1869.

Griwnack, K. [Region of the mines of Bogoslovsk.] *Journ. d. mines russes.* No. 4. Pp. 1-86. 1887.

———. [Iron ore deposits in the Districts of Serguinsk and Oufaley.] *Journ. des mines.* Nos. 4, 5, pp. 27-60; 245-278. 1888.

Groddeck, Dr. Alb. von. Die Lehre von den Lagerstätten der Erze. Pp. i-xii, 1-351, cuts 119. 8vo, Leipzig. 1879.

Gruner, E. Jun. [Situation of the Iron Industry of Styria and Carinthia.] *Ann. Mines, sér. 7, t. ix,* pp. 471-518. 1876.

Guignet, E., and G. Ozorio de Almeida. [Nickeliferous Meteoric Iron found in Santa-Catarina, Brazil.] *Comp. Rend. t. lxxxiii,* p. 917. *M. Daubrée* adds a note on the meteoric iron of Disko, Greenland. 1875.

Gumælius, Otto. [Age of the Iron Ores and their use as guiding beds.] *Æfvers. K. Vet. Akad. Förhandl. Stockholm,* pp. 30. 1875.

"Swedish ores of iron are in stratified deposits of the same age as the enclosing rocks. Nearly all Swedish geologists believe this. Kjerulf, a Norwegian, advocates the eruptive hypothesis. Certain ores contain carbonaceous matter and indicate that organic vegetable and animal life existed at an earlier period than is generally supposed. The redurites show the absence of reducing agencies of this sort and are older." Gives analyses of the various types of Swedish ores. Does not mention titaniferous ores nor gabbro. Cannot find anything corresponding to Laurentian and Huronian.

———. [Iron-ore deposit of Næverhougen, Norway.] *Geol. Fören. Stockholm Förhandl.* Bd. ii, no. 28, p. 565, map. 1875.

"The chief mass of the ore lies in eutritic rock, closely following the strike of an overlying limestone. Elsewhere the ore is in the limestone itself." (*Geol. Record.*)

———. [Iron-ore deposit of Næverhougen, Norway, No. 2.] *Geol. Fören. Stockholm Förh.* Bd. iii, pp. 322-335. 1877. An answer to a paper by **Corneliusen.**

"Discusses whether the ore occurs as an eruptive mass or as a layer."

———. [Ore-deposits and products in Scania.] *Geol. Fören. Stockholm Förhandl.* 1, pp. 235-237. 1874.

Habets, A. [Hematite Deposits of Furness and Cumberland.] *Rev. Univ. des Mines, t. xxxvi,* pp. 329-335. Abstract of a Paper by M. Würzburger, read at the meeting of the Iron and Steel Institute, Sept., 1874.

Hackett, C. A. Note on the Arvali Series in Northeastern Raj-putana. *Rec. Geol. Surv. Ind.,* vol. x, p. 84, map, 1877.

Hahn, O. *Zeitschr. d. d. geol. Gesellsch.* Bd. 15, 1863, p. 249.

Haidinger, —. *Leonhard's Jahrb.,* 1848, p. 63. On Iron Ore Deposits in the Eastern Alps.

———. *Leonhard's Jahrb.,* 1849, p. 209. On Iron Ores of the Eastern Alps.

Hall, Prof. Frederick. Ores of Iron and Manganese in Vermont. *Am. Jour. Sci.,* i, iii, 1821, pp. 57, 58.

Hall, C. H. Mining in the Marquette Region. *Jour. U. S. Assoc. Char-coal Iron Workers,* vol. iv, no. 5, p. 293. 1883.

"The iron ore in the lake Superior region is found deposited in lenses, like the seeds in a pumpkin. This expression comes nearest to anything with which I can compare it. It is found in lenses of unequal size. There are no veins, but simply pocket depos-

its. We have, of course, some general idea of where the ore may be found, but, generally speaking, we do not know where the ore is until we find it by exploration."

Hall, Charles E. Laurentian Magnetic Iron Ore Deposits in Northern New York. 32d Ann. Rep. N. Y. State Museum, pp. 135-140.

Haniel, J. [Jurassic Iron Ores of Germany.] *Zeitsch. deutsch. geol. Ges.* Bd. xxvi, Heft. 1, pp. 59-118, 1874.

Harden, J. W. The Brown Hematite Ore Deposits of South Mountain, between Carlisle, Waynesborough, and the Southeastern edge of the Cumberland Valley. *Trans. Amer. Inst. Min. Eng.*, vol. i, pp. 136-144, 1873.

"The ore, which lies along the slopes and valleys of the spurs and ridges of the mountain, associated with clays and sands, is the residue of decomposition of the slates and limestones (Silurian) and has generally a red gravelly covering of from 5 to 20 feet thick, evidently a surface wash." (*Geol. Record*, 1874, p. 117).

Harrington, B. J. Notes on the Iron Ores of Canada. *Iron*, n. ser. vol. v, pp. 550, 648, 806; vol. vi, pp. 74, 106; vol. vii, pp. 9, 41, 70, 106.

———. Notes on Chrome-Garnet, Pyrrhotite and Titaniferous Iron Ores. *Canad. Nat.*, n. s., vol. ix, No. 5, p. 305, 1880.

Heim, A. Untersuchungen über den Mechanismus der Gebirgsbildung,

Harrington, B. J. Geology of Canada. 1873-4. p. 194, *et seq.*

Says that the various ores of iron occur both in veins and beds in Canada. "None of the Canadian magnetites, so far as I am aware, have ever been regarded as eruptive, at least by officers of the Geological survey."

"Considering the origin of our sedimentary magnetites, the question arises as to whether they were originally deposited as such, or in some other form and afterwards altered to magnetite. It seems possible that, in some cases, beds may have been formed by the accumulation of iron sands, just as they are forming in the Gulf of St. Lawrence to-day, the material being derived from the disintegration of pre-existing crystalline rocks. Such beds we should expect to contain not only magnetite, but ilmenite, and it is well known that in many cases ore on being pulverized may be more or less completely separated into a magnetic portion containing little or no titanitic acid, and a non-magnetic portion consisting essentially of ilmenite. It seems, however, probable that in general their origin has been similar to that of the modern bog and lake ores. Deposits of magnetites, as a rule, do not continue of uniform thickness for any great distance like the enclosing rocks, and this is just what might be expected if we suppose them to have originally occurred as bog or lake ores which accumulated in local hollows or depressions. No ore, moreover, would be more readily converted into magnetite than bog ore, on account of the considerable proportion of organic matter which the latter contains."

Harriss-Gastrel, —. Report on the Iron and Steel Industries of the United States. *Reports by Her Majesty's Secretary of Embassy and Legation, Commercial*, No. 18 (1874), part ii, 8vo. Pp. 129-816.

Hartley, Edward. *Geol. Sur. Can.*, 1867-69. Appendix to Reports on the Pictou Coal Field, p. 183. Speaking of "specular iron," which he considers to be "probably Upper Silurian," Mr. Hartley says:

"The specular iron appears to exist in true fissure-veins, but of no considerable size, at any locality which I have seen. In many cases the rocks holding it appear to be much shattered, and the specular iron, with a compact granular quartz as a veinstone, appears to fill the fissures, which are often confined to a particular bed of rock, and sometimes so numerous, that the entire bed contains a large percentage of the ore, and may be considered as a single deposit. * * * The minor veins are often of several inches in thickness, and are included in a light greenish-drab granular quartzite, which they traverse in the most irregular manner."

Speaking of spathose ores he says (*l. c.* p. 185):

"Whether this deposit should be considered a bed or a vein, is still a matter of uncertainty, but it appears to be conformable to the stratification."

Hauchecorne, —. *Zeitschr. f. d. Berg-, Hütten- u. Salinenwesen im preuss. Staat*. Bd. 16, B, p. 199.

Hauenfels, —. *Berg-, u. Hüttenm. Jahrb. d. k. k. östr. Bergacad.* 1864, Bd. xiii, p. 214.

Hauer and Fötterle. *Uebers. d. Bergb.*, p. 72. Iron deposits in the Eastern Alps.

Hausmann, —. *Reise d. Scandinavien*, pt. ii, p. 138; pt. iv, p. 69. Refers to Iron Ores of Sweden.

"Hausmann thinks that the iron in most of the lake-ore deposits originated from decomposed iron pyrites in greenstones; and considers it probable that many of the ores in the lakes have been formed by the decomposition of neighboring bog-ores." Von Cotta, Ore Deposits, p. 462.

———. *Berg- u. Hüttenm. Zeitung*. 1850, p. 83, 102.

Hawkins, John. On the Phenomena of Intersected Lodes. *Trans. Roy. Geol. Soc. Cornwall*, vol. ii, p. 49, 1822, *Vid.*, also p. 290.

Hayden, F. V. Geological Survey of the Territories, 1869, pp. 78, 193.

———. Geological Surveys of the Territories, 1870, p. 14.

Hayes, Dr. A. A. Native Iron from Liberia, South Africa. *Annual of Scientific Discovery*, 1856, p. 304.

Pure native iron, not meteoric, but probably occurring as a deposit by itself.

Head, Jeremiah. Iron Mines of Bilbao. Abstract in *Brit. Assoc. Adv. Sci.*, 1887, p. 861. Printed in *extenso* in *Industries* for Sept. 16 and 23, 1887; also in *Iron and Iron and Coal Trades Review* of Sept. 9 and 16.

Discusses at length how the ores may have been formed, and considers the origin as aqueous by the action of water containing carbonic acid.

Heath, —. Natural History of Scilly and Cornwall, 1750.

Hector, James. On the Geology of the Country Between Lake Superior and the Pacific Ocean, etc. *Quart. Journ. Geol. Soc.*, 1861, xvii, 388-445.

———. Remarks on Hematite and Spathic Iron Ores. *Trans. N. Zealand Inst.*, vol. xii, proc. p. 424, 1880.

Heddle, M. F. Chapters on the Mineralogy of Scotland, vii, Ores of Manganeese, Iron, Chromium and Titanium. *Trans. Roy. Soc. Edinburgh*, vol. xxx, pp. 427-466, 1882.

Helmersen, G. Der Magnetberg Blagodat am Nordlichen Ural, 1837. Advocates eruptive theory.

Henkel, J. F. Pyritologia oder Kieshistorie. *Leipzig*, 1725. An English translation was published in *London* in 1757.

Hensoldt, H. Meteorites and what they Teach us. *Am. Geol.*, vol. iv, pp. 23-38; 73-83, 1889.

Considers the Ovifak iron as directly erupted in its present metallic state, and suggests that:

"The interior of the earth is in all probability a vast metallic mass consisting mainly of iron," p. 83.

Henwood, W. J. Notice of a Geological Survey of the Mines of Cornwall. *Phil. Mag. and Annals of Philos.*, n. s., vol. x, p. 358, 1831.

———. On the Electric Currents Observed in some Metalliferous Veins. *Jameson's Edinburgh New. Phil. Journ.*, vol. xxii, p. 270, 1837.

———. A Lecture on the Phenomena of Metalliferous Veins. *Jameson's Edinburgh New. Phil. Jour.*, vol. xxii, p. 152, 1837.

———. *Trans. Roy. Geol. Soc. Cornwall*, vol. v, 1843.

Henwood, Wm. J. On the Native Copper of Lake Superior. On Metalliferous Deposits and Subterranean Temperature. *Trans. Geol. Soc. of Cornwall*, vol. viii, part i, 1871, pp. 385-489.

Heurteau, E. [Geology and Mineral Resources of New Caledonia.] *Paris*. Abstract in *Bull. Soc. Géogr. Paris*, 6 sér. t. xii. pp. 648-653. 1876. *Ann. Mines*, sér. 7, t. ix, pp. 322-454, pl. vii-x. 1876.

Heusler.— (Note on a newly opened Oolitic Iron Ore in the Jurassic Formation of the Teutoburger Wald.) *Corr.-Blatt nat. Ver. preuss. Rhein*. vol. ix, pp. 113-119. 1882.

Hewitt, Abram S. A Century of Mining and Metallurgy in the United States. Philadelphia. 1876.

Hilt, —. *Zeitschr. f. d. Berg-u. Hütten- u. Salinenw. im preuss. Staat*. Bd. xiii, 1865, p. 13.

Hind, Henry Y. Report on the Exploration of the country between Lake Superior and the Red River settlement, 1858, 425 pp., with maps.

———. Report on the Assiniboine and Saskatchewan Exploring Expedition. 1859, 201 pp., with maps.

———. Narrative of the Canadian Exploring Expedition. London, 1860, i, 494 pp.; ii, 472 pp.

Hitchcock, Dr. Edward. Geology of Massachusetts. 1833.

On pages 350-362 are ideas which contain the germ of the theory adopted by Profs. Irving and Van Hise for the Huronian ores of Wisconsin, viz., original deposition in oceanic waters as a carbonate, and subsequent change to an oxide.

"At all these localities the ore is found in distinct beds in the strata; and sometimes it has a slaty structure, having every appearance of a contemporaneous origin with the rock. * * * * This porous quartz and the hydrate of iron are very common throughout the talcose slate of Hoosac Mountain, and the iron results, if I mistake not, as already mentioned, from the decomposition of the carbonate."

———. Outline of the Geology of the Globe. Boston, 1853, 162 pp, with maps.

———. Geology of Vermont, 1861. Vol. 1, p. 236. Supposes hematite to be derived from limestones containing siderite.

"The carbonate exists, as we have seen, in the limestone beneath the hematite beds, also in the mica and especially the talcose schists. Generally the specular and magnetic ores are found in schists that have undergone a more powerful metamorphic action than those underlying the hematites. The inference, therefore, is certainly fair, that whatever rock contains the carbonate of iron especially, and indeed any of the other species of iron, may prove to be a source of the brown hematite. In some instances already mentioned, we find the exposed portion of the vein or bed transformed into hematite, but not denuded; yet in general the disintegrated portion has been more or less swept off by water and redeposited. Hence we should say that no one rock, but all that contain other ores of iron, especially the carbonate, may have originated the hematite."

———. Geology of Vermont. Vol. 2, pp. 814-829. 1861. History of Iron Workings on p. 823. Considered Iron Ore deposits to occur in beds, not veins.

Hochstetter, Fr. v. *Zeitschr. d. d. geol. Gesellsch.* 1864, B. xvi, p. 342.

Hodge, James T. On the Mineral Region of Lake Superior. *Proc. Am. Assoc. Adv. Sci.*, 1849, ii, 301-308; *Ann. Sci. Disc.* 1850, 260, 261.

Hoernes, R. Ein alter Eisenbergbau bei Graz. *Verh. k.-k. Geol. Reichs.* pp. 138-140. 1882.

Hoefler, Prof. H. [Coal and Iron Ore Deposits of North America.] *Vienna.* 1878. Report of the Austrian commissioner to the Centennial Exposition.

Hoffman, J. G. De Matricibus Metallorum. *Leipzig.* 1738.

Hofman, Fr. *Karsten's Archives.* 1833. Vol. 6. p. 238.

Holland, D. [Metalliferous Deposits of Corsica.] *Bull. Soc. Géol. France.* 3 sér. t. iv, pp. 30-34. 1876.

Holley A. L. Notes on Iron Ore and Anthracite Coal of Rhode Island and Massachusetts. *Trans. Am. Inst. Min. Eng.* vi., 224, 1877.

Hopkins, —. Researches in Physical Geology. *Trans. Cambridge Philos. Soc.* vol. vi. pt. 1.

Horlivy, E. Ueber das Vorkommen der Brauneisensteine in Rudnitz. *Zeitschr. berg-hütt. Ver. Karnten.* Bd. xii. p. 277. 1880.

Houghton, Douglass. Metalliferous Veins of the Northern Peninsula of Michigan. *Am. Journ. Sci.*, 1841, (1), xli, 183-186; *Trans. of the Assoc. Am. Geol. and Nat.*, 1840-42, pp. 35-38; *Edinburgh New Phil. Journ.*, 1842, xxxiii, 201, 202.

"Dr. Houghton conceives these to be veins of sublimation, or in other words, to be simple fissures filled from below by the metal in a vaporous state."

Hudleston, W. H. Excursion to Northamptonshire. *Proc. Geol. Assoc.*, vol. iv, No. 2, pp. 123-124, 1875.

"The Ironstone of the Northampton Sand is described as formed by the substitution of iron for lime in the original rock, the carbonate of iron having been afterwards chiefly changed into hydrated peroxide."

Hughes, T. W. H. Notes on some of the Iron Ores of Kumaon. *Rec.*

Geol. Sur. Ind., vol. vii, pt. 1, pp. 15-20. See also Supplement to *Gazette of India*, Aug. 22, pp. 1466-68, 1874.

———. Second Note on the Materials for Iron Manufacture in the Raniganj Coal Field. *Rec. Geol. Surv. Ind.*, vol. vii, pt. 3, pp. 122-124, 1874.

———. Note on some of the Iron Deposits of Chanda, Central Provinces. Supplement to *Gazette of India*, Aug. 22, pp. 1489-1491, 1874.

———. The Wardha Valley Coal Field. *Mem. Geol. Sur. Ind.*, vol. xiii, art 1, pp. 154, 3 maps, 1877.

Hull, E. Blenheim Iron Ore. Geology of Country Around Woodstock. *Mem. Geol. Sur.*, 1857.

Hull, Prof. Edward. Notes on the Hematites of Counties of Cavan and Longford. Read before Royal Dublin Society June 3, 1872.

"It (the hematite), therefore, does not occur as a lode or vein, traversing the strata in a highly inclined position, but rather in the form of lenticular beds of extreme irregularity."

———. Explanatory Memoir to Accompany Sheets 21, 28 and 29 of the Maps of the Geological Survey of Ireland. 8vo. *Dublin*, 1876.

"The iron ores (hæmatites) and the lithomarge are extensively worked, and are very valuable; they appear to be of lacustrine origin."

Hunt, Robert. Mineral Statistics of the United Stock of Great Britain and Ireland, for the year 1874, with an Appendix. Pp. xv, 279, 8vo. *London*, 1875. The character of the iron ores from the various districts is stated.

———. British Mining. Pp. 956, 8vo. *London*, 1884.

Hunt, Thomas Sterry. *Amer. Nat.* April, 1875; *Am. Jour. Sci.* (ii) xxxi 392-414. 1861.

———. Chemistry of the Primeval Earth. *Smithsonian Report*, 1869, p. 191.

In this paper is advocated the theory that the beds of iron ore in the Archæan are indications of the existence of vegetable life at that early period.

"The evidences of this reducing and dissolving action of organic matter are met with not only in the fire-clays and ironstones of the Carboniferous system, and among secondary, tertiary and modern deposits, but on a grand scale in the Laurentian system, where great thicknesses of sediments are found almost destitute of iron, while beds of iron ore more extensive than at any subsequent periods are evidences of the abundance of organic matters at that early time."

———. *Geol. Sur. Can.* 1866-69, Part 8. Abstract in *Can. Nat. and Quart. Journ. Sci.* n. s. vol. vi, No. 1, Sept. 1871. Discusses *Iron Sands, etc.*, and has some interesting historical accounts of early iron workings in the United States

———. *Chemical and Geological Essays*, p. 22. *Rep. Prog. Geol. Can.* 1866-69, pp. 261, 269. *Can. Nat.* vol. vi, p. 79, 1872; vol. vii, p. 127.

———. The Origin of Metalliferous Deposits. *Trans. Am. Inst. Min. Eng* 1872, i, 413-426.

———. On the Crystalline Rocks of the Blue Ridge, and on their decomposed condition. *Proc. Bost. Nat. Hist. Soc.* vol. xvi, part 2, pp. 116, 117. 1874.

"These consist of hornblende and micaceous schists, completely decomposed to a depth of 50 feet or more, being changed to a reddish unctuous clay, with interbedded layers of quartz, showing the original inclination of the rocks. The removal of the iron-oxides is said to be the source of the large deposits of hydrous iron-ores found at the foot of the Blue Ridge in the Appalachian Valley. The decomposition is supposed to have taken place at very ancient times, when there was a highly carbonated atmosphere." *Geol. Record*, 1874, p. 121.

———. The Geology of the North Shore of Lake Superior. *Trans. Am Inst. Min. Eng.*, 1873, ii, 58, 59.

———. Geognostical History of the Metals. *Trans. Amer. Inst. Min. Eng* vol. i, pp. 331-346. 1874.

"Divides the crystalline stratified rocks of Eastern North America into four groups, lithologically and stratigraphically distinct—Laurentian, Norian (or Labradorian, upper Laurentian of Logan), Huronian and Montalban, (gneiss and mica schist of the White Mountains), and thinks it probable that other like formations of crystalline rocks may have been almost entirely swept away. The Laurentian is remarkable for deposits of crystalline iron-ore, chiefly magnetic, the ores occurring in beds or masses of contemporaneous deposition. The Norian is remarkable for titaniferous iron-ores. In the Huronian are the great deposits of hematite and magnetite of Lake Superior;

chromic iron-ores seem to be characteristic. The distribution of ores in other rocks is also noticed." *Geol. Rec.* 1874, pp. 120, 121.

Hunt, T. S. The Coal and Iron of Southern Ohio, considered with relation to the Hocking Valley Coal Field, and its Iron Ores, etc., with a view of the coal trade of the West. 8vo., pp. 78. *Salem.* 1874.

———. *Natl. Acad. Sci.* Nov. 1874.

As to the origin of brown hematite ores, Hunt is of the opinion that they were once beds of pyrites in *Huronian* schists, now decayed.

———. The Development of Our Mineral Resources. *Harper's Magazine* 1875, h. 82-94.

———. The Cornwall Iron Mines and some Related Deposits in Pennsylvania. *Trans. Amer. Inst. Min. Eng.*, vol. iv, pp. 319-325, 1876.

"Believes these ores to come from the alteration of deposits of carbonate, and in many cases, of sulphuret of iron, oxidized *in situ*," since they are in many places interstratified with the brown hematite.

———. *Am. Assoc. Adv. Sci.* 1876.

"The crystalline character often exhibited by these so-called Primal slates was noticed by Rogers, who ascribed it to their subsequent alteration by intrusive rocks. A careful study of this series has, however, convinced me that its detrital beds include, in many parts, deposits of chemical origin, such as beds of crystalline magnesian limestone, often holding serpentine, chloritic, steatitic and micaceous schists and especially great beds of magnetic and more rarely specular or red hematite iron ores. * * * The aspect of these ores and their associated rocks is unlike that of the other crystalline series already mentioned." "These strata include deposits of carbonate of iron and others of pyrites, from the alteration of one and the other of which, in the deeply decayed portions of the strata (now converted into clays) have been formed the great quantities of hydrous iron ores which characterize, throughout the whole extent of their outcrop, the Primal and Auroral strata. These are the Lower Taconic rocks of Emmons."

———. On the recent formation of quartz, and on Silicification in California. *Am. Jour. Sci.* (iii.), vol. xix, pp. 371-2. 1880.

———. The Genesis of certain Iron Ores. Abstract of a paper read at the Boston meeting A. A. A. S., Aug. 28, 1880.

"The changes of siderite and pyrite under atmospheric influences were next considered. The latter, by oxidation yields, as is well known, ferrous sulphate. Its frequent conversion by sub-aerial decay into limonite was conceived to be due to the intervention of water holding carbonates, which conjointly with oxygen, changes it into hydrous peroxide (limonite) the latter often retaining the form of the pyrites. The transformation of carbonate of iron into hydrous peroxide is a familiar fact.

Limonite ores may thus be produced in three ways. They are sometimes formed by the peroxidation and precipitation of dissolved ferrous salts, as in the bog-ores; but more frequently from the alteration *in situ* of deposits of pyrite or siderite. Such as these are the "limonites" which mark the outcrops of beds or veins of pyrites in the decayed crystalline rocks of the Blue Ridge. The similar ores found in the decayed Taconic schists of the great Appalachian Valley can be shown to be due in some cases to the alteration of included masses of pyrites, and in others to the alteration of similar masses of siderite, both of which species are found in the unaltered Taconic rocks, as indeed at various other horizons in the geological series."

———. Coal and Iron in Southern Ohio: the Mineral Resources of the Hocking Valley. Account of its Coals, Iron Ores, Blast Furnaces and Railroads. 8vo. pp. 152. *Boston.* Map. 1881.

———. Coal and Iron in Alabama. *Trans. Amer. Inst. Min. Eng.* Boston Meeting, Feb. 1883.

"As regards the brown hematites * * * these hydrous ores have been generated, as has been shown by myself and others, by the alteration *in situ* of interstratified masses and layers, in some cases of carbonate of iron and in others of pyrites, included in the more or less argillaceous strata now changed to clays."

———. *Trans. Amer. Inst. Min. Eng.*, vol. iv, pp. 319-325. 1876.

"The decayed crystalline schists which there (Pennsylvania) contain the limonites were not Huronian but Taconic. (2nd Penn. Report, E. Pt. 1, p. 203.) The crystalline, magnetic and specular ores * * * found along the borders of the Mesozoic basin of Pennsylvania are not to be confounded with the ores of Huronian or of Laurentian age, but alike by their geological position and their mineralogical associations differ from those * * * and appear to belong to a distinct ore-bearing horizon. * * * They are, all of them, really contemporaneous deposits included in the Primal slates (H. D. Rogers) which correspond to a portion of the Lower Taconic series of Emmons, and belong, in my opinion, to a lower horizon than the Potsdam sandstone of the New York system." "These magnetic and specular ores of the Primal slates have very close geological relations with the brown hematites of the region, some of which belong to the same Primal slates. These ores, which I believe to come from the alteration of deposits of carbonate, and in many cases, of sulphuret of iron, oxydized *in*

situ, are, in certain deposits of the region, interstratified with crystalline magnetic and specular oxides; the whole being imbedded in the clays which have resulted from the more or less complete decomposition of the enclosing crystalline rocks."

Hutton, Dr. James. Theory of the Earth, 2 vols. 1795.

It is inferred that the materials which fill the mineral veins were melted by heat, and forcibly injected in that state into the clefts and fissures of the strata. This idea was particularly applied to iron ore deposits. *Vid.* Illustrations of the Huttonian Theory of the Earth by Prof. John Playfair, 1802. Also Report on the State of Knowledge Respecting Mineral Veins, by John Taylor, *Brit. Assoc. Rep.*, 1833, p. 10.

Igelstrom, L. J. Bidrag till fragan om malmernas af Tabergstypen geognosi. *Geol. Fören. Stockholm Förh.* Bd. vi, pp. 319-322, 1883.

———. *Berg-, u. Hüttenm. Zeitung.* 1866, p. 21.

Irving, Roland D. On some Points in the Geology of Northern Wisconsin. *Trans. Wisc. Acad. Sci.*, 1873-74, ii, 107-119.

"In this (central) portion of the group occur all the famous ores of the Penokie Range—and indeed all the ores whose existence is yet known—these ores being never intercalated lenticular masses, independent of the enclosing rocks, but simply portions of the great (Huronian) group—five hundred feet thick—of magnetic and specular schists, carrying a larger portion of the oxides than the general run."

———. Note on the Stratigraphy of the Huronian Series of Northern Wisconsin; and on the Equivalency of the Huronian of the Marquette and Penokee Districts. *Am. Jour. Sci.*, 1879, (3), xvii, 393-398.

———. Mineral Resources of Wisconsin. *Trans. Amer. Inst. Min. Eng.*, vol. viii, 1880.

———. Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region. *Am. Jour. Sci.*, (iii) vol. xxxii, Oct. 1886.

"Two classes of theories have been maintained to account for the iron ores of the Lake Superior region. According to one of these, these ores, with more or less accompanying rock material, and particularly the jaspery schists so often associated with them, are in the main of eruptive origin; according to the other they are of sedimentary origin, the original sedimentation having been mechanical or chemical, or both, according to different theories. On the eruption theories subsequent chemical alteration is allowed to come in to some extent to explain present conditions, as it is also with some of the sedimentation theories; but the latter theories appear to appeal in the main to a regional metamorphism as the cause of present conditions.

Those who have maintained the theories of a sedimentary origin have relied chiefly upon the common intimate interlamination of siliceous and ferruginous materials; upon the manifest restriction of the ores and jaspery schists to definite stratigraphical horizons; upon their interfolding with other members of the same series, and upon their apparent gradation in places into plainly fragmental deposits. These conditions being taken to indicate original sedimentation, different authors have imagined the unaltered deposits to have been argillaceous carbonates like those of the coal measures, to have been brown ores like those found under bogs, or accumulating in shallow lakes, at the present day, or to have been magnetic iron sands like those of modern sea-shores. All of these theories appear to regard the silica of the jaspery schists and ores as having been sand; its present non-arenaceous, non-fragmental condition being taken to be the result of metamorphism.

Advocates of an igneous origin for the iron ores and associated jaspers have been few, and it is noteworthy that their observations have been confined to the Marquette region, where the disturbances have been great, and where the difficulties are consequently greater than in other regions. In support of an igneous origin for these materials, which are supposed on such theories to have been intruded as bosses, or to have formed overflows at the time of the accumulation of the associated strata, have been cited particularly: (1) an irregularity of contact of the ore and jasper with the adjoining schists; (2) the projection of stringers of ore and jasper into the adjoining schists; (3) the induration of the adjoining schists; (4) the curvature of schistose cleavage by ore intrusions; and (5) the occurrence of fragments of ore and jasper in an immediately overlying quartzite of the same series, this indicating their existence in their present conditions of induration prior to the accumulation of this quartzite. (M. E. Wadsworth, *Bull. Mus. Comp. Zool.* Vol. vii, No. 1.) On this theory the lamination of the ore and jasper is taken to be probably a fluidal structure, and the interbedding of ore and jasper with the schists to be the result of a contemporaneous flowing of lava. Having carefully examined the localities cited by the last advocate of an eruption theory as proving the above facts, I feel able to say that the occurrences, save the last named (5) are trivial matters occurring within the space of a few inches, or feet at most, and that all are more easily applicable—as irregularities in original deposition, as irregularities due to the crumpled condition of the strata, or, and this chiefly, as due to infiltration of iron oxide and silica into cracks in the rocks, and the replacement of rock material by such substances—on theories of original sedimentation of the iron beds than on those of an eruptive origin, the last named point, viz.: the occurrence of fragments of the banded jasper in the immediately overlying quartzite, deserves more consideration, since it certainly indicates that to some extent at

least, these substances had reached their present condition at an early day. But cooling from a state of fusion is not the only way of reaching rapidly the indurated condition, and a former fused condition seems to be negatived at once by the nature of the material—quartz and iron oxide. * * * Again, the silica, which frequently forms so prominent a part of the ferruginous schists, and which is at times jaspery, but is far more frequently cherty or even chalcedonic—a point hitherto quite unrecognized in publications on this subject—presents every evidence, both in the thin section and in the field, of a chemical origin. In the thin section, in that it shows ordinarily no trace of a fragmental texture, even when relatively coarse-grained, and in that it approaches more commonly to the peculiar chalcedonic or even amorphous forms known to occur only with silica deposited directly from solution; besides which it traverses and follows the banding indifferently and in such a manner as to place its secondary nature beyond all doubt. In the field, in that the jaspery or chalcedonic silica, while in the main closely interbanded with the more ferruginous portions of the rock, is seen also to intersect the bands, or even to appear in the shape of a cement to a brecciated mass of fragments of the interbanded materials. All theories of a formation of these ferruginous rocks by metamorphism, or recrystallization *in situ*, from some sort of sedimentary deposit, seem to regard the jaspery or cherty material as representative of a fragmental siliceous ingredient in the original deposit—either a quartz sand or a fine “siliceous silt.” On these theories this substance has been recrystallized from the fragmental condition. The facts above cited refute any such explanation, and prove incontestably the chemical origin of the silica. We may cite in addition, moreover, the fact that in these siliceous iron rocks themselves there is at times an admixture of fragmental quartz, which in the thin section is always sharply defined as an original ingredient, and easily distinguishable from the water-deposited silica. The latter is frequently identical with that cherty material which has often taken the place of large bodies of limestone among the unaltered formations.

“These considerations leading to the rejection of a metamorphic origin for any of these materials, as others had previously led to the rejection of an igneous origin, it followed that we were thus restricted to some theory which should account for the precipitation of most of them essentially in their present conditions, with perhaps some slight internal rearrangement, or to one in which the production, from some form of sedimentary deposit, of the conditions now obtaining, should be assigned to metasomatic processes, carried out in part at least, at a very remote period. * * * While we have, perhaps, in the deposition from some modern siliceous springs, a slight analogy to the interstratification of iron sesquioxide and silica, this analogy is, after all, but slight, and any theory of deposition from springs fails entirely to secure in its support any modern analogues for the various magnetic and actinolitic schists whose production must be explained. Again, there is nothing in the structure of these deposits to indicate spring deposition, and everything to indicate deposition in bodies of water. But of the formation of such deposits by chemical deposition in bodies of water we certainly have no modern instances. * * *

“Later, as further study developed the fact that the least altered forms of the ferruginous schists contain a considerable proportion of some carbonate—the amount of carbonate increasing inversely with the amount of disturbance and alteration—the idea of a possible formation of these rocks by chemical deposition approximately in their present conditions gave place to views which included the idea of a replacement of some rock, originally dolomitic or calcitic, by siliceous and ferruginous substances. * * * That the original carbonate was itself ferruginous was an idea that presented itself, but had been abandoned. But a suggestion from Professor Pumpelly led to a further chemical examination with regard to this point in which much new material was included. The result was the establishing the general feriferous character of the original carbonate; while further quantitative analyses made in the chemical laboratory of the U. S. Geological Survey showed that it is often even a genuine siderite, though magnesian. This point once established, all of our field and laboratory observations seemed to fall suddenly into line, and to establish the truth of an hypothesis long since advanced, viz: that these ferruginous rocks were once carbonates analogous to those of the coal measures; though the advocates of this hypothesis can hardly have realized the ground it could be shown to cover, and they certainly did not have any conception of the nature of the altering process.”

Jackson, Dr. R. M. S. Nittany Valley Iron Ores, 1838-39.

Considered them to be deposits *in loco originali* of the iron (as hydrated peroxide) set free from the limestone or dolomite rocks during their gradual erosion and dissolution. *Vid. Am. Jour. Sci.*, (3), 1875, ix, p. 437.

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———. Volcanoes. 1881. p. 319. Mr. Judd says:

"A careful study of all the facts of the case by Lawrence Smith, Daubrée and others well acquainted with the phenomena exhibited by meteorites, has led to the conclusion that the large iron-masses of Ovifak, as well as as particles of metallic iron diffused through the surrounding basalt, are all of terrestrial origin, and have been brought by volcanic action from the earth's interior. * * * * These researches appear to warrant the hypothesis that the interior of our globe consists of metallic substances uncombined with oxygen, and that among these metallic substances iron plays an important part. Our globe, as we know, is a great magnet, and the remarkable phenomena of terrestrial magnetism may also not improbably find their explanation in the fact that metallic iron forms so large a portion of the earth's interior."

Julien, A. A. The Genesis of the Crystalline Iron Ores. *Proc. Acad. Nat. Sci. Phil.* 1882. p. 335.

"In an age which admits its special indebtedness for material advancement to the industries connected with the manufacture of iron, and in a country in which these industries have been so vastly developed as in this, the question of the origin of that metal has long possessed, and must always retain, a high degree of interest. So far as relates to the limonites, turgites and bog-ores, the question has met with a satisfactory answer in the theory of the concentration of these ores by the percolation of organic acids, as fully presented in the writings of Bischof, Hunt and others; especially as the

process can be actually observed and studied in progress in the lakes, marshes and bogs of the present day. But the mode of genesis of the crystalline ores—hematites, magnetites, menaccanites, and their mixtures—enveloped partly in the sedimentary strata and chiefly in the still more ancient crystalline rocks of Archæan age, can be only inferred from analogies. Nor can the problem be considered as solved by any or all of the numerous theories which have so far been advanced. These theories may be naturally divided into two classes, as they may refer the iron-ores, enclosed in the subterranean strata, to an extraneous or to an indigenous origin.

A. THEORIES OF EXTRANEOUS ORIGIN.

To begin with the former, we have

1 *Meteoritic fall.* This startling theory has been suggested to account for the enormous mass of martitic specular iron-ore, claimed to be the most extensive known single deposit of iron-ore on the continent, that of Cerro de Mercado, two miles from Durango, Mexico. 'Cerro de Mercado is a mountain, one mile long, one-third of a mile wide, and from 400 to 600 feet in height. The ore-surface of the mountain aggregates over 10,000,000 square feet, but there are indications that the ore is not all above ground, and the the engineers' report declares it to be an enormous aërolite, half imbedded in the level plain on which it lies.' Such a view is sufficiently controverted by the mineralogical constitution of the mass, and its structure—immense veins of specular iron-ore standing nearly vertical.' (B. Silliman, *Am. Jour. Sci.*, 1882 (iii), xxiv, 375; and J. Birkinbine, *Chicago Min. Jour.* 1882, ii., No. 4, p. 184.)

2. *Eruption as dykes.* According to this genetic view, the crystalline iron ores have been extruded from the interior in a pasty condition like a lava, through fissures in the superficial strata. (J. D. Whitney, *The Metallic Wealth of the U. S.*, p. 433.)

This theory has been recently further developed in reference to the banded jaspery iron ores of Michigan, and it has been advanced that the banding and lamination of these ores are similar in character and origin to those strongly marked in rhyolites, furnace slags, etc. (M. E. Wadsworth, *Proc. Bost. Soc. Nat. Hist.*, 1880, xx, 470; and *Am. Jour. Sci.*, 1881, (iii), xxii, 403.) The mineralogical constitution and infusibility of these ores, their distinctly sedimentary lamination, etc., clearly testify to the unsoundness of these hypotheses. (J. D. Dana, *Am. Jour. Sci.*, 1881, (iii), xxii, 320, 402; J. S. Newberry, *Sch. of Mines Quarterly*, Nov. 1880.)

3. *Sublimation into fissures.* The inconsiderable crusts of specular oxide, which have been observed in the vicinity of volcanoes, such as Vesuvius, have certainly no relation to the enormous *bedded* masses distributed throughout the world, at a distance from volcanic centers.

B. THEORIES OF INDIGENEOUS ORIGIN.

The theories of this class differ in ascribing the origin of iron ores to either chemical or mechanical agencies. Nine chemical theories have been proposed.

4. *Concentration from ferriferous rocks or lean ores*, by the solution and removal of the predominant constituent, *e. g.* silica, by means of thermal solutions. Indeed it has been shown (J. P. Lesley, Report on Brown Hematite Deposits of Nittany Valley, Pa., R. Pumpelly, *Geol. Surv. Mo., Prelim. Rep. on Iron Ores*, 1872, 8 *et seq.*) that a concentration, in a similar way, of the ferriferous constituent, in the lower Carboniferous limestones and dolomites of the Mississippi basin through the removal of the more soluble calcium carbonate by carbonated waters, has apparently produced extensive deposits of limonite, *in loco originali*. But there is no evidence of the relation of any of the crystalline iron ores, enclosed in sediments of plainly sub-marine origin, with any such subaerial process. Even were the theory satisfactory in regard to the pure ores, the essential question remains unanswered, viz., the genesis of the original 'ferriferous rocks or lean ores' themselves.

5. *Saturation of porous strata, e. g., of sandstone*, by infiltrating solutions carrying iron oxide. (Emmons, *Nat. Hist. N. Y.*, iv, 94, 1842.) This theory, however applicable to certain rock masses rich in hydrated ferric oxides, can account neither for the concentration of the huge and pure bodies of the true ores, nor for the alternation of siliceous and ferriferous laminae and layers in the lean ores.

6. *Infiltration into subterranean chambers and channels*, depositing pipe-ores and limonites in widened crevices and joints of the more recent limestones or other sedimentary rocks, or in cavities overlying impervious strata. (F. Prime, Jr., *Am. Journ. Sci.*, 1875, (iii), ix, 433.) The lenticular form, laminated structure, intercalation of the matrix, enclosure of the ore-bodies in the bedding-planes and other facts, markedly distinguish the crystalline ores from the limonites formed by such a process.

7. *Decomposition of pyrite*, and other ferruginous minerals, enclosed in decaying schists and transfer of the iron-oxide in solution as ferrous sulphate. (T. S. Hunt, *Nat. Ac. Sci.*, Nov., 1874.) The precipitation of the iron-oxide has been sometimes attributed to simple oxidation, more usually to the production of ferrous carbonate, by reaction between the ferrous sulphate and the calcium carbonate of the limestone, afterwards converted into limonite by oxidation and hydration. (G. Bischof, *Chem. and Phys. Geol.*, i, 236; F. Prime, Jr., *loc. cit.*; W. B. Rogers, *Geol. Penn.*, 1868, ii, Pt. ii, 722, 729.) This theory has had only local application, even to the limonites, and its connection with the crystalline ores is rendered improbable by the absence of associated limestones, or, if present, of evidences of their erosion, etc.

8. *Derivation from original deep-sea deposits* of hydrous ferric oxide; or of ferrous carbonate, dehydrated by subsequent heat, and deoxidized by hydrogen. (J. P. Lesley, *The Iron Master's Guide*, p. 374, 1866.) By a modification of this theory, the jasper-ores have been connected with the ferruginous and manganiferous nodules which have been dredged from the surface-layer of the deep-sea ooze of our present ocean-bottoms. (W. O. Crosby, *Proc. Bost. Soc. Nat. Hist.*, 1879, xx, 168.) All the evidence so far gathered, however, shows no correspondence between the phenomena; the ferriferous contents of the ooze consisting of irregular crusts and nodules, never continuous nor interlami-

nated with silica. On the other hand there is abundant evidence that the strata associated with the crystalline iron ores are mostly shallow-water or shore deposits, in large part conglomeritic.

9. *Deposit from springs*, by oxidation and precipitation from solutions of ferrous carbonate, on exposure to the air at their issue. (G. Bischof, Chem. and Phys. Geol., i, 155-157, 166-167.) Such deposits, it is admitted, are local and limited, and the theory can have no bearing on the ordinary wide-spread crystalline ores.

10. *Alteration of diffused ferric oxide*, disseminated through sediments, into ferrous carbonate, in presence of vegetable matter, and its accumulation in particular layers by processes of filtration and segregation. (W. B. Rogers, Geol. Penn., 1868, ii, Pt. ii, 737). The vague processes thus invoked to account for the accumulation of ores are not accepted as satisfactory, even for the carbonates of the coal measures, lying in definite planes. Nor do the sheets and beds of crystalline ores usually show the irregular characteristics which may be attributed to processes of segregation.

11. *Metamorphism of ancient bog-ores*. The reference of the crystalline iron ores to this origin has been thus stated by Dr. Hunt: 'I see no reason for assigning any other than a sedimentary origin to the magnetic and specular iron ores of the crystalline schists; nor do I conceive that the conditions under which they were deposited differed essentially from those which at the present day give rise to limonite and ochre.' (Letter of Dr. T. S. Hunt, 1858, quoted in Lesley's Iron Masters' Guide, p. 365. See also Vanuxem, Nat. Hist. N. Y., Geol., 3d District, p. 267.) Again he observes: 'The organic matters reduce the peroxide of iron to a soluble protoxide, and remove it from the soil, to be afterwards deposited in the forms of iron ochre and iron ores, which by subsequent alteration become hard, crystalline and insoluble.' (Chem. and Geol. Essays, p. 22.) * * * *

In opposition to this theory, in its reference to subaërial bogs or marshes (see Dana, J. D.), it must be considered that the enclosing and associated strata bear universal testimony, both in their contents and the form of their superificies, to their submarine mode of deposit. On the other hand, if the bog-ore theory were applicable to these ores, every ore-bed would imply a terrestrial plane for the reception of the subaërial bog deposit, i. e., for every ore-lens a corresponding elevation above the sea-level and ensuing subsidence of the entire underlying stratum. On the contrary, no evidence has been shown in the Archæan strata of any subaërial surface; all appear to be submarine sediments, and that still more ancient rocky terrane which formed the coast whose debris, poor in iron, was deposited or strewn over the ancient Laurentian sea, and upon whose surface bog-deposits may have rested, seems to have been entirely buried up beneath later sediments. * * * *

12. *The metamorphism of ancient lake-deposits of limonite* passing into hematite, corresponding to the oolitic 'fossil ore' of the Clinton group of the Upper Silurian, to the 'mustard seed' ore described by Sjörmalm*, which is deposited near the banks of the present Swedish lakes, etc.. (B. Von Cotta, Ore Deposits, 249, 284, 461; The Geologist, 1863, 36.) This 'Lake ore' theory (Dr. J. S. Newberry, 'The Genesis of Our Iron Ores,' Sch. of Mines Quarterly, Nov. 1880,) seems to be valid for a large number of huge deposits of the crystalline ores, and also satisfactorily accounts for the abundant presence of apatite in many ore-beds. It may be fittingly applied, therefore, in explanation of the phenomena seen in those deposits which contain a notable amount of calcium phosphate; most of those which consist of hematite, or of magnetite passing into or occasionally enclosing hematite, * * * and the beds of magnetite which present the botryoidal and concretionary aspect and radiated structure of limonite. * * * On the other hand, the poverty or almost entire absence of phosphorus and sulphur in certain ore beds, and the extreme abundance of titanic acid, free alumina, garnet, olivine, etc., in others, demand some other explanation.

Two mechanical theories are yet to be considered.

13. *Violent abrasion and transport*. This theory may be best stated in the words of its author:

'That the Azoic period was one of long-continued and violent action cannot be doubted, and while the deposition of stratified beds was going on, volcanic agencies, combined with powerful currents, may have abraded and swept away portions of the erupted, ferriferous masses, re-arranging their particles and depositing them again in the depressions of the strata.' (J. D. Whitney, Metallic Wealth of the U. S., 434.)

This theory of Whitney was supplementary to his main theory of volcanic eruption of the ferriferous masses, rich in native iron. But to this Lesley properly objects that such secondary deposits would be conglomeritic and also contain metallic iron.

14. *'Concentration and metamorphism of iron sands.'* This theory, proposed in 1874 by B. J. Harrington, Mr. Julien advocates at considerable length, closing as follows:

'No concentration of titanic acid has ever been found in limonites or bog-ores. These facts seem significant of the insufficiency of any chemical theory to account for the origin of all the iron-ores. In conclusion, it may be inferred that the mode of genesis of a bed of magnetic iron-ore may be determined with some probability by the following diagnosis:

When the ore retains structural characteristics allied to those of limonite, or encloses masses of hematite, a chemico-organic origin is probably indicated.

When the ore is exceptionally free from phosphorus, or is rich in titanic or chromic acid, or is closely associated or mixed with granular garnet or olivine, a mechanical origin may be inferred."

Karpinsky, A. On the Origin of the Iron Ore of the Donetz Basin. (In Russian). *Rep. Russ. Geol. Com.*, vol. 1, pp. 1-12, 1883.

*Mr. Julien has here evidently mistaken the literal translation of the term *lake-ore* (Sjörmalm) for the name of a supposed writer on the subject. *Ed.*

Karsten, C. J. B. Ueber feuer-meteor. *Acad. Sci. Berlin.* Jan. 13, 1853.

Quoted by Lesley in *Iron Mfrs. Guide*, p. 343. "Many a meteor may have been so oxidized while lying countless ages on the surface of the earth as to have lost its original nature and form; and many a massive meteor, thrown off when the rind of its mother orb burst on cooling, and itself reaching the earth so quickly that its heat was still very great, may have cooled under the action of the atmospheric oxygen into a very different body from what it was in space. Many a block of stone may lie on plain or mountain side among the earth-born rubbish of the cliff, without exciting a suspicion of its heavenly origin, as many a mind of the divinest mould lives unsuspected in a savage state or walks unrecognized among the crowds of city life. There may have been ages of its history when clouds of these meteors of both kinds met the earth, and spread themselves in blocks or masses or flattened layers on its surface. And if so, subsequent deposits must have covered them up, and denudation may have swept them away again or made sections of them, exposing their outcrops like terrestrial beds of rock or iron ore. The geologist at all events must be prepared to encounter cases of this kind."

"Such Karsten thinks to be the nature of the curious iron deposit near Thorn in Central Europe, discovered by Herr Grodski, of Wolfsmühle, in 1852, and covering at least 700 acres of his ground, within four inches of the top of the soil. The ore outside was the common brown and yellow iron stone, but when freshly broken was peculiar of its kind, looking as if half melted, partly compact, partly porous, a black lava-like substance, glassy and shaggy in its whole appearance. But the first steps of an analysis showed that it could have been no result of artificial smelting, mixed as the native iron was with an olivine mineral. The mixture of unchanged meteoric iron and meteoric stone was so fine that when the mass was reduced to powder a magnet would not take up all the iron free of olivine. No iron works were ever heard of in the neighborhood of Thorn, nor could a vast number of them ever have accomplished such a result. The ore overlies the whole area in bars or plates two or three feet long, three to six inches wide and two or three inches thick, shoved against and between each other in one place where there is a ravine and water course for 170 feet of face, but elsewhere separated by greater or less spaces; all lie on sand and scarce one appears above the soil. Most of the meteors seem therefore to have fallen in the ravine, where the cubic contents of only half the mass as measured would amount to 4,800 cubic feet or 360 tons, and the whole mass as known in 1853 could not be less than 1,000 tons, the fall of, which one mile further west would have destroyed the whole town of Wolfsmühle had it then existed and the tradition of the event would have been indelible from the oral or written history of the land. * * * Thousands of tons of iron falling from miles of height upon a frozen earth must have imitated an earthquake very well." * * * "Following up the clew which Karsten finds for us in this meteor fall of Thorn, we reach the ground of a clear judgment upon all so-called native iron masses that they may and therefore must be meteoric, for here are masses of pure iron ore certainly meteoric *without cobalt or nickel*, and here also are such masses in process of passing into red oxide of iron ore. Hence whenever a pure or native iron mass is found, by which must be carefully understood not pure iron ore, but pure iron—not pure oxide of iron whether specular or magnetic, but pure iron itself—it must be held of heavenly origin, fallen recently, and already in the process of becoming red earth. Hence the impossibility of finding meteors of pure iron embedded as fossils in the rocks of any but the most recent times."

(Lesley loc. cit. p. 345.)

Kayser, E. A. Geological and Mining Report on the Etheridge Gold-field, N. Queensland. *Queenslander*, vol. x, n. ser. No. 11, p. 24. Includes notes on red and brown oxide of iron.

Keilhau, —. Gaea Norvegica. *Christiania*, 1838. vol. i, pp. 61, 73, 107, 109, 125. On Iron Ores of Norway.

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Kjerulf, T., and Tellef Dahll. Geology of the vicinity of Arendal. *Noves Jahrb. f. Min.* 1862. pp. 557-581.

Kendall, J. D. The Hämatite deposits of Whitehaven and Furness. *Coll. Guard.* vol. xxviii, pp. 157, 230, 374, plan and 18 figs. in text. 1874.

"Examines the theories which have been imagined to account for the formation of the deposits, and dismisses that of the igneous origin, believing that the hämatite was originally deposited as carbonate, partly replacing the limestone, and partly in previously existing caverns. Thinks that the hämatite is younger than the Carboniferous limestone, and older than a great part of the Permian." *Geol. Record.* 1874. p. 372

———. The Hämatite Deposits of Whitehaven and Furness, (with Discussion.) *Trans. Manch. Geol. Soc.* vol. xiii, pp. 221, 286, 288, 304. 1875.

———. Hämatite in the Silurians. *Quart. Jour. Geol. Soc.* vol. xxxii, pp. 180-183. 1876.

———. On the Hämatite Deposits of West Cumberland. *Trans. N. Engl. Inst. Eng.* vol. xxviii, pp. 107-154, pls. xviii-xxxiii.; Discussion, pp. 219-234. 1879.

"It is concluded that the ore has not always been deposited in cavities, but that it has taken the place of such parts of the rock as have been more easily affected by chemical action. Considers that the deposition of the ore is due to a ferriferous solution depositing the iron as fast as it took up the limestone. The iron was derived from a volcanic source. * * * This theory of the deposition of the ore being due to the replacement of the rock associated with the veins may be extended to the hæmatite deposits of other parts, as well as to many other metalliferous deposits, including those of Galena at Alston Moor." (*Geol. Record.*)

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Kimball, Dr. James P. *Am. Jour. Sci.* (ii.) xxix, pp. 290-303. 1865.

———. *Am. Jour. Sci.* (ii.) vol. 39, No. 117, May, 1865, p. 301.

"Beds of specular conglomerate are of frequent occurrence throughout the Iron region of Northern Michigan, consisting of a paste of specular peroxyl of iron, through which are disseminated fragments of jasper, and rounded pebbles of specular iron ore which usually differ from the paste in texture, a difference very perceptible among ores of any one class even within narrow limits of distribution. These conglomerates not unfrequently resemble breccia in the angularity of the jasper fragments which they contain; but the pebbles of specular peroxyl, although sometimes obscure in a matrix of the same nature, commonly serve to indicate the detrital origin of these beds. That they are derived from local detritus is evident from the fact that the jasper fragments are not rounded, while the particles of softer specular iron ore are worn but slightly. They seem to be of littoral formation and to have been derived from dismembered and crumbled deposits of successive lamina of jasper and iron ore—similar to those deposits distinguishable in the bosses of the region. The specular conglomerate invariably exists under circumstances of true bedding and is traversed by parallel joints splitting the imbedded pebbles. It occurs interstratified with talcose and argillaceous schists quite as regularly as the homogeneous ores. * * * It will be observed that while the smaller plications furnish the most available and complete evidences of the stratigraphical conditions of the ferriferous schists, every exposure of them in quarries or natural outcrops, conveys the same character of evidence, but upon a scale far more extended, and generally requiring allowance for superficial vicissitudes, and a large degree of denudation. Even if space permitted, I conceive it to be unnecessary to multiply instances of this evidence. It has been shown that the iron ores of the Huronian series in Michigan are essentially schists and heavy-bedded strata in which none of the phenomena of aqueous deposits formed by precipitation from water on the one hand, or by detrital accumulation on the other, are wanting. They exhibit not only stratification, anticlinal and synclinal folds, but are invariably traversed by systems of joints and at many points exhibit a perfect slaty cleavage. * * * From a stratigraphical point of view, while evidence is elsewhere often obscure, the Huronian greenstone, schists and iron ores of Northern Michigan, in the absence of close attention to their special chemical conditions, exhibit sedimentary and metamorphic phenomena adequate to render quite untenable, it is believed, the theory of the exotic character of any portion of them."

———. Fossil Red Hematite Ore of Bedford Co., Penn. 1882.

———. Geological Relations and Genesis of the Specular Iron Ores of Santiago de Cuba. *Am. Jour. Sci.* (iii.) vol. xxviii, Dec. 1884. Considers various iron ores to have been formed in different ways as will appear from the following quotations. One principal origin for iron ore in Cuba is said to be by chemical substitution of ferric oxide for the carbonate of lime in coralline limestones:

"Proof of the coralline parentage of the iron ore bosses is the preservation in nearly all of them of fossil corals, or at least of casts of coral. Such casts are found toward the outer parts of the ore bodies in what may be called their transition parts."

In a paper upon the iron ore ranges of the Santiago district of Cuba read before the *Am. Inst. Min. Eng.*, xiii. (1884 or 1885), Prof. Kimball presents the same theory more at length and divides the ores of Cuba into three classes according to their mode of origin. "The large bodies of hematite or specular oxide, together with associated ferruginous

aggregates,—in part of magnetic oxide, are secondary products from the decomposition of basic eruptive rocks." After describing in detail the process of weathering and alteration to which these rocks would naturally be subjected, and explaining the concentration of ferric oxide, he adds: "The best of the iron ore bodies, including those of the East Mine and the developed ore-bodies of West Mine, hills, are mainly, if not indeed wholly, replacements of coralline limestone." * * * "The iron ore bodies of the alpine district east of Santiago, are exceptional from the fact that they are attributable to the immediate alteration of eruptive rocks, and that resulting residues, including an important portion of their original ferriferous contents, have been preserved almost *in situ*.

The other great bodies of ferric oxide in North America, like the Huronian deposits of Michigan and Wisconsin, are similarly derived from the decomposition of highly, but less basic rocks of *metamorphic* and not of direct eruptive origin. Such stratified specular iron ore bodies are believed to owe their existence to the accumulation by precipitation of ferric oxide from basins of water receiving the drainage from such basic rocks. * * * The source therefore of the Archaean crystalline, or so-called primary, iron ores, including most deposits of magnetite, was basic rocks comparatively poor in ferrous oxide and rich in earthy silicates." * * * "The second type of ore referred to weathers in prismatic blocks and possesses the structure of dense trappan rocks, such as abound in the form of dykes both within the syenite and the altered overlying iron-bearing rocks. Ledges of this description are uniformly rich at exposed surfaces, and so is their detritus or float. Such occurrences are the result of the decomposition *in situ* of basic eruptives by the dismemberment of silicates, followed by the concentration of ferric and magnetic oxides. This action is essentially superficial." "It will be perceived that, unlike the great Archaean deposits of specular oxide, both classes of ore deposits above described have undergone a process of concentration without going through the intermediate stage of sedimentation. In other words they are products in the one case of the segregation of ferric oxide, in part from immediate sources; and in the other of alteration *in situ* of protoxide basic rocks by peroxidation of their most unstable base, namely, ferrous oxide."

The third class of iron ore deposits is intimately associated with an overflow of epidiotic diorite and its origin is not fully settled in Mr. Kimball's mind.

———. Siderite-basins of the Hudson River Epoch. *Am. Jour. Sci.* (iii) xl, p. 155. 1890.

"This remarkable series of ore-basins seem to owe their origin to depressions in an in-shore mud-bottom fed by waters from decomposing basic rocks. From such waters ferric oxide was precipitated along with mechanical sediments from the land and calcareous sediments from the sea."

Kinahan, G. H. Notes on some of the Irish Crystalline Iron Ores. *Proc. Roy. Dub. Soc.* vol. iv, part vi. 1884. pp 306-317.

He first states that the lodes and lenticular masses of the crystalline ores, as well as carbonates, "are due to the decomposition of organic matter and carbonic acid." He quotes Le Conte in this connection. Further on in the same paper are advocated in a confused way the "infiltration," "Pyrites," "Ascension" and "Sublimation" theories for various ores, and the reader is left in doubt as to which theory is really supposed to be the correct one.

Kindler, —. Poggendorff's Annalen der Physik und Chemie, vol. xxxviii, p. 203. 1836.

Was the first to call attention to the effect of decaying vegetable matter upon the solubility of ferric hydrates.

King, W. and Foote, R. B. *Mem. Geol. Sur. India.* 1865. Deals largely with the immense Iron ore deposits of India, which are said to be among the wonders of the world.

Kingston, J. T. Account of the Iron Mine at Haytor, Devonshire. *Phil. Mag. and Annals.* n. s. vol. 3, No. 17. 1828. p. 359.

Kitchell, Dr. W. Annual Report on Geol. Sur. N. J. 1856.

"Having described the geological occurrence of magnetic iron ore in this district, we are led to consider its origin, and to refer it to the particular class of metalliferous deposits to which it belongs—whether it is of aqueous or igneous origin—whether it occurs in the form of stratified or unstratified deposits.

"That they cannot be referred to the unstratified deposits appears evident from the facts stated in describing the different forms in which the ore occurs: nevertheless it has been maintained by some that they are true veins of igneous origin, which implies that they extend to an indefinite length and breadth, that they differ in character from the rock in which they are situated, and have been formed subsequent to it. Such deposits do not usually coincide with strike and dip of the strata in which they are inclosed, but generally cross the line of stratification and frequently send off branches of greater or lesser dimensions, at different angles from the main veins. The body of the vein is in most cases separated from the walls on either side by decomposed rock called selvage.

"It will be observed that none of these phenomena can be applied to the magnetic ore deposits of this district: nor can they be veins of segregation, which implies that the material of which they are composed has been eliminated or collected together from the surrounding rock by some chemical action. Such deposits are composed of a gangue, or materials different from the surrounding rock, and are very irregular in their form.

"Stratified deposits imply that they are included within sedimentary rocks, that they

are of aqueous origin, and that they coincide in geological position and in the mode of formation with the rocks in which they are situated. From the facts that have already been stated, they must be referred to this class of metalliferous deposits.

"That the rocky formation of this district, including the gneiss, the hornblende and mica schists, the magnetic iron ore, and the quartz-feldspathic rocks, are of metamorphic origin there can be but little doubt; consequently it is conceived that they were originally deposited by water in a horizontal position; that they are composed of materials derived from pre-existing rocks; and they were subsequently disturbed in their position and altered by metamorphic agencies, which have caused them to assume their present form and position. The origin, therefore, of these deposits of magnetic iron ore is identical and contemporaneous with the rocky strata in which they are inclosed." (Geol. of N. J. for 1868, p. 534, quoted from Annual Report, 1856.)

"Its (Limonite) origin is undoubtedly from sulphides of iron in the adjacent gneissic rocks, which by atmospheric agencies have been converted into soluble sulphates, and these latter when in solution have, by chemical reaction on the magnesian limestones, produced precipitates of the peroxide of iron, and solutions of sulphates of lime and magnesia." (Geol. N. J. 1868, p. 663.)

Kjerulf, Th. and Dahl, Tellef. *Neues Jahrb. f. Mineral.* 1862, p. 557.

Klaproth, ---. On the Mineral and Chemical History of the Fossils of Cornwall. 1787. Translated by Dr. I. G. Groesche.

Kleinschmidt, ---. *Berg- u. Hüttenm. Zeitung.* 1869, p. 357 and 373.

Klemenetz, D. [Results of the expedition to the upper part of the Abakane and the Altai.] *Mem. Soc. géogr. Sec. de la Sibérie de l'Ouest.* xiii, livr. 1. Pp. 15-25, 55-56. 1886.

Klupfel, ---. *Berg- u. Hüttenm. Zeitung.* 1871, p. 22.

Koch, Fr. C. L. Kupfer- und Eisenerze am Lake Superior. *Zeit. deut. Geol. Gesells.*, 1851, iii, 355-358.

———. Studien des Gott. Vereins Bergm. Freunde. vi, 1-248. 1854. *Mining Mag. New York*, 1853, i, 261-268.

"The iron rocks he would consider as upheaved from great depths, or else to have suffered great metamorphism by the influence of igneous masses. That they (the iron rocks) may be simply the quartz rock impregnated with oxide of iron is thought probable."

Kohler, W. Zum alter der Oberharzer Erzgänge. *Mitth. nat. Ver. Maja*, n. F. Bd. ii, p. 123. 1880.

Koenen, A. Von. Ueber das alter d. Eisenerz von Hohenkirchen. *Nachricht. K. Ges. Wiss. Göttingen.* 1883.

Krantz, ---. *Karsten's Archiv.*, 1840, vol. xv., p. 347. On Iron Ores of Elba, says:

"The iron-ore-deposit, occurring on Cape Calamita, rises, where most extended, to a height of 900 feet above the sea. The bed is mostly limonite, and iron-ochre, at the surface, but at a slight depth passes into specular iron. Large fragments, partly in place, partly detached, designate the entire extent of the deposit, on whose southeast side native magnets are found near the sea. I observed, so far as was possible, that the magnetic iron forms a bed on the eastern limit of the iron-deposits." Von Cotta, *Ore Deposits*, p. 355.

Krasnopolsky, A. [General chart of Russia. Sheet 126. Geological researches on the western slope of the Urals.] *Mém. Com. Géol.* Vol. xi, No. 1. Pp. 1-484.

———. [Preliminary account of investigations made in 1885 on the western slope of the Urals.] *Bull. Com. Géol.* No. 6, pp. 263-281. 1886.

Krotov, P. [Geological investigations on the western slope of the Urals in the Districts of Solikamsk and Tscherdyn.] *Mém. Com. Géol.* T. vi, pp. 1-534. 1888.

Krause, F. M. The Lal Lal Iron Ore Deposits. *Ann. Rep. Ballarat School Mines.* pp. 45-50. 1881.

Kudematsch, ---. *Jahrb. d. geolog. Reichsanst.* 1852. p. 4. Iron Ore in the Eastern Alps.

Kuhn K. A. Handbuch der Geognosie. *Freiberg.* 1836.

Russ, Henri. Note sur quelques gites minéraux des terrains oxfordiens et sur l'âge de la formation de fer spathique d'Allevard. *Bull. Soc. Sci. nat. Sud.-Est.*, t. i, pp. 25-32. 1882.

———. Sur les filons de fer spathique du Canton d'Allevard. *Bull. Soc. Géol. France*, sér. 3, t. ix, p. 699. 1881.

Langlois and Jaquot. *Annales d. Mines.* vol. xx, p. 109. 1851.
On Iron Ore in France.

Lapham, Increase A. The Penokie Iron Range. *Wis. State Agr. Soc. Trans.*, 1858-59, v., 391-400, with map.

Lasius, G. O. S. Beobachtungen über die Harzgebirge. *Hanover.* 1787.

Laspeyres, —. *Neues Jahrb. f. Mineral*, 1869, p. 512.

Lassen, T. [List showing the Relative Age of the Minerals in 145 Rock-specimens from the Iron-ore Mines at Arendal, Norway.] *Nyt. Mag. Nat.* Bd. xxiv. Heft. 3. p. 227. 1878.

Laube, G. C. [Notes on Scandinavia.] *Lotos*, Feb. Mar. 1874. Noticed in *N. Jahrb.* 1875. p. 319.

Lawton, Chas. D. Mines and Mineral Interests of Michigan. *Iron Agitator.* vol. vi. No. 45. 1886.

——. Mineral Resources State of Michigan. 1886. pp. 20, 21.

"The ore occurs in the rocks with which it is associated in every manner of form of deposit. In common phraseology it is spoken of as the ore vein. But the deposits partake very little of the characteristics of a vein proper. They are generally very irregular, pockets or lenses, and there is little certainty when or where they may occur, or to what extent they may continue. * * * The Lake Superior region is, geologically, of great antiquity. In times long past it has been the scene of great elemental catastrophe. The rocks have been thrown up, depressed, metamorphosed—subjected to every manner and degree of pressure, contorted and twisted, imposed, superimposed, and then reversed; broken up, dissolved, and again formed and resubjected to the stupendous forces of the elements. So that, plainly, it requires all the skill of the trained observer, aided by every appliance of modern science, to unravel the skein."

"The origin of our ore deposits is still a mystery; of hypotheses there have been plenty, but they are based upon half knowledge, conjecture, too little observation and too few facts. The great forces which were at play in the formation of these ore-beds, —chemical, mechanical, igneous—have left their traces in the rocks and the record can be deciphered; the perseverance and the skill of the microscopist may master the problem. I would not say that very much that is important and valuable has not been accomplished in the geological study of the Lake Superior region, but the kind of work is required that Mr. Wright, the new State Geologist, has recently entered upon, the work of the micro-lithologist, to interpret the history which the rocks themselves have for ages held locked in their constituent crystals. It is a key which, in the hands of the properly skilled interpreter, in possession of all the facts, shall unlock the final secret of the rock formations of this most remarkable region."

Lebour, G. A. On the Geological Relations of the Secondary Iron ores of France. *Trans. N. Engl. Inst. Eng.* vol. xxv, pp. 59-78. 1876.

Le Conte, Joseph. Elements of Geology, 1878. Like Hunt and Newberry, Le Conte considers iron ore in all ages to have been produced by organic matter, and that it is a sure sign of the existence of life in Azoic times.

"We have already explained (p. 136) how iron-ore is now accumulated by the agency of decaying organic matter. We have also shown that if the organic matter is consumed in doing the work of accumulation, the iron-ore is left in the form of iron peroxide; but if it is accumulated in the presence of excess of organic matter, it retains the form of ferrous carbonate. We will now give additional evidence, taken from the occurrence of iron-ore in the strata of the earth, that the same agency has accomplished the same results in all geological times.

1. Immense beds of iron-ore are found in the strata of all geological ages; but, wherever we find them, we find also associated a corresponding amount of strata, decolorized or leached of their iron coloring matter. Contrarily, whenever we find the rocks extensively red, we find also an absence of valuable beds of iron-ore. We are thus led to conclude that the iron-ore of iron-beds has been washed out of the strata, which are thereby left in a decolorized condition.

2. That this has been done by the agency of organic matter is shown by the fact that, wherever we find evidences of organic matter, whether in the form of fossils or of coal, we find the sandstones and shales are white or gray—i. e., leached of coloring matter. Conversely, red rocks are always barren of fossils or of coal. For example, all the sandstones of the coal-measures, or of all other strata containing coal, are gray, while the Old Red sandstone below the coal and the New Red sandstone above the coal, and in fact, all red sandstones, are very poor in fossils or evidences of organic matter of any kind. Thus, evidences of organic matter and the discoloring of the strata, and the accumulation of iron-ore, are closely associated as cause and effect.

3. In all the strata, whether older or newer, in which there is no coal, i. e., in which there is no excess of organic matter in a state of change, the iron-ore is peroxide (ferrie oxide); while in coal-measures of all periods, whether Carboniferous, or Jurassic, or Cretaceous, or Tertiary, or in all cases where there is organic matter in excess in a state of change (not graphite), the iron-ore is in the form of carbonate protoxide, or ferrous carbonate (FeCO_3).

Therefore we conclude that both *now* and *always* iron-ore is, and has been, accumulated by organic agency; again, that both now and always there are and have been, three conditions of iron-ore, each associated with the absence or presence in smaller or larger quantities of changing organic matter: 1. It may be universally diffused as a coloring matter of rocks and soils, and unavailable for industries; in this case there has been no organic matter to leach it out and accumulate it. 2. It may be accumulated as ferric oxide; in this case there has been organic matter only sufficient to do the work of accumulation, and was all consumed in doing that work. 3. It may be accumulated as ferrous carbonate; in this case there is an excess of organic matter in the form of coal. * * *

But, in any case, organic matter has been the agent; and, therefore, in this case as in all other cases, iron-ore is the *sign* of organic matter, and the *measure* of the amount of organic matter consumed in its accumulation. There are, therefore, three signs of the previous existence of organisms used by geologists; they are *coal*, *iron-ore* and *fossils*.

Lehmann, J. G. Abhandlung von den Metallmuttern. Berlin. 1753.

Leithe, —. In *Kranz' Jahrb. f. d. Berg- u. Hüttenm.* 1852, p. 234. Iron ore deposits in the Eastern Alps.

Leon, E. De. The Mineral Resources of the Southern States of the American Union. *Iron*, vol. iv, pp. 674, 706. 1874.

Le Play. *Comptes Rendus.* Oct. 1844. Considered the magnetic iron ores of Nijny Tagilsk of eruptive origin.

Lesley, J. P. Mont Alto Lignite. *Amer. Phil. Soc.* Mar. 1865.

———. Iron Manufacturers' Guide. Pp. xxxiv, 772, 1866.

Mr. Lesley discusses at length the various theories that have been advanced to account for the origin of the various ores of iron. He advocates strongly a chemico-sedimentary origin.

On p. 334 he says: "Chemical action is now known to be a sufficient cause for the grandest metamorphic phenomena. * * * Good geologists look upon mountains of granite or sienite no longer as upbursts of molten matter from the interior of the planet, but as sedimentary rocks hardened and crystallized by gentle heat and acid water, and even regard veins of quartz as infiltrations from above rather than ejections from beneath. The occurrence of the precious metals, copper, silver, lead and even gold is explained by many who are authorized to speak as a precipitation in crevices from overlying waters or as original deposits at the bottom of the ancient seas.

The prejudice instilled by our familiarity with *iron in a molten state* has left it hitherto an exception to this rule; as a prejudice in favor of the igneous origin of all metallic veins obliged geologists to adopt the theory of gaseous impregnation to explain "fahlbands" or rocks through which pyrites is disseminated. But such a prejudice cannot last. Evidence is accumulating year by year sufficient to remove all doubt of the common sedimentary origin of iron even under forms which once were universally accepted as volcanic."

On p. 357 Mr. Lesley remarks concerning theories which he quotes from Prof. J. D. Whitney: "It appears from the foregoing that Mr. Whitney accepts both the eruptive and sedimentary theories of the formation of the primary iron ores and applies the former to unknown invisible masses antecedent to and now deeply buried under all, even the oldest rocks which appear upon the present surface; masses of far greater size and depth than the greatest yet discovered proportionate to the greater scale of all volcanic action in that pre-azoic day, and offering their sides and tops to such erosion and solution as would of course happen in such unsettled times, and be sufficient for producing the vast sediments of iron which have been taken for volcanic outbursts of the molten metal. But there is a fatal difficulty in the way of this hypothesis. These ore-beds are not *brecciated*. Deposits of the kind imagined would be *conglomeritic*; blocks of pig iron would be seen scattered through strata of granite." [In reference to this criticism of Whitney by Lesley, Dr. Wadsworth remarks (Bul. Mus. Comp. Zool. Geol. Ser. 1, p. 13.) "Here, again, he has entirely misunderstood Prof. Whitney's views, which were that the great masses of ore in the Lake Superior district were eruptive where they now are, and were never sedimentary deposits, while associated with and derived from them are the *brecciated* and *conglomeritic* ores, as well as other sedimentary beds. If it is necessary, the pig iron can doubtless be found at Ovikafak, Disko, in the basalt."]

"The hypothesis halts precisely where a similar sedimentary hypothesis for the origin of coal halts; it is unable to explain the solid homogeneous outspread and evidently local character of the deposit. But setting this aside, it is a mere hypothesis. No such masses of cast iron have ever been seen in the world. The beautiful theory of Sir Humphrey Davy so charmingly explained and illustrated by Sir Charles Lyell in the xxxiii chapter of his Principles, according to which the metallic bases exist in purity in the molten nucleus of the earth, and at the crust are alternately oxidized and deoxidized by the oxygen and hydrogen of the sea water and the air, giving rise to steam pressure, earthquakes, volcanic lavas, pumice dust and gaseous exhalations, is perfect in its way; but it does not help us to conclude that planetary masses of pure iron have ever been ejected through the crust. * * *

When we remember how many observers have pronounced the Missouri iron mountain solid masses of pure metal rising from the central regions of the earth in the shape of cones, thrusting their points through the crust precisely the same as men described the Mauch Chunk summit mine before the floor of that mineral horizontal bed of coal was discovered and its shape revealed—we may withhold for a while our unqualified assent to these descriptions and suspect that future research may modify the appearances presented now. But even if they still continued to be well adjudged

expressions of the possibility of volcanic iron they will not cease to be rare exceptions to the general rule, and therefore supporters only to that extent of the ejection theory. They will still leave the sedimentary theory all the ground it asks for innumerable beds of crystallized iron in metamorphic rocks; original productions at the bottom of a sea; not subsequent segregations in fissures."

"It is not intended to deny that iron is involved in all volcanic operations, with silica, alumina, lime, magnesia and other metallic oxides and non-metallic elements. On the contrary, no element is more universally present in the world, and therefore none can suffer a greater variety of contingencies and transformations. Iron appeared in the lavas of Etna during the eruption of 1855 in two forms; the magnetic and the non-magnetic. The early lavas of that eruption were gray, much more crystalline and strongly magnetic. The later lavas were dark, with a glassy coating, and had no action upon the magnet. Both were found to contain nearly the same amount of iron. Both contained also phosphoric acid (1.4 and 2.2 per cent). But there is need of some strong counteracting prejudice in favor of a truer view of the primary so-called veins of iron against the old prejudice that every unexplainable appearance among stratified rocks must be an issue of red-hot or fluid mineral from some conjectural reservoir of volcanism underlying even the quietest portions of the earth-crust, a prejudice which lies at the bottom of men's credulity to the cunning miner's maxim, 'It will improve as you go down.'"

On p. 370 Mr. Lesley continues in the same vein, speaking of experiments made by M. de Sanarmont: "All this goes to sustain the judgment of the eclectics who accept the igneous origin of lava rocks of every age and yet are disposed to acknowledge the increasing evidence in favor of the chemical and chemico-sedimentary origin of perhaps a majority of the silicious, dolomitic and metallic, and even a few of the trachytic and trappan members of the earth's crust, and certainly of almost all the so-called primary iron ores. The red specular or primary red hematite beds of the St. Lawrence are confessedly sedimentary."

"Beds of carbonate of iron have been considered the natural chemical iron precipitations of the ocean charged with river solutions of the sulphate. But iron deposited from sea water, when the water was charged with organic matter in ancient as in modern days, must have fallen in the form of a peroxide, and must have been mixed with a sediment from river and ocean currents of a very varied mineral character, principally silicate of alumina and carbonate of lime and magnesia."

On p. 376 Mr. Lesley says: "It is in these hypersthene Huronian strata just underneath the Potsdam sandstone or the base of the lower Silurian paleozoic rocks, that the great magnetic iron ore beds of northern New York, sometimes charged with phosphate of lime, appear, and always in the form of chemico-sedimentary beds, never in the form of igneous veins."

Many more passages might be quoted from Lesley's admirable treatise, but the following will suffice: "The titanium in titaniferous iron is no more evidence of the locally igneous origin of titaniferous iron than nickel in a lump of iron is of its meteoric origin, nor as much; for Dr. Mazade of Venice has detected titanium with zircon, molybdenum, tin, tungsten, tantalum, cerium, yttrium, glucinium, nickel and cobalt in the mineral waters of Neyrac, in France. (*Ann. Sci. Dis., Boston, 1853, p. 203*)."

———. The Iron Ores of South Mountain in Cumberland Co., Penn. *Proc. Amer. Phil. Soc.*, May, 1872, January, 1873.

———. Report on Brown Hematite deposits of Nittany Valley, Pa.

———. Titaniferous Iron Ore Belt, near Greensboro, N. C. Read before the *Am. Phil. Soc.* June, 1871. pp. 139-158.

Mr. Lesley says that the ores are in rocks similar to those which contain the titaniferous ores of Canada and Sweden; and that at times these rocks approach a greenstone or diorite in appearance and composition. He advocates a sedimentary origin for these and all other primary ores of iron: "These ore-beds are not ore-veins, for they do not cut through the rocks crosswise. They have no well-defined walls; they have no selvages; there is no gangue-rock different from the rocks on each side; they have, therefore, not been formed in crevices subsequently in a later age after the up-tilting of the formation; they have neither been ejected volcanically from below, nor infiltrated aqueously from above, nor secreted chemically from the wall-rocks; in a word they are not at all 'veins.' On the contrary they are 'beds,' beds deposited, like the rest of the rocks, in water; deposited in the same age with the rocks which hold them; are in fact rock-deposits highly charged with iron; and they differ from the rest of the rocks of the formation in no respect excepting this: That they are more highly charged with iron."

In fact, all of our primary (magnetic and other) iron ore beds obey this law. They are merely certain strata consisting more or less completely of peroxide of iron, with more or less intermixture of mud and sand, which when crystallized, fell into the shape of feldspar, hornblende, mica, quartz, etc., etc."

Lesley, J. P. and E. V. D'Invilliers. Report on the Cornwall Iron Ore Mines. Annual Report Geology of Pennsylvania, 1885, pp. 491-570. Map and plates.

"The Cornwall magnetic iron ore mass is as sedimentary a formation as the brown hematite ore masses in other parts of the state, and was like them originally a formation of magnesium limestone beds, some thick and hard, others very thin, laminated, soft, and easily acted upon by water."

Levallois ——. *Annales d. Mines.* 1849, p. 241. *Mémoires de la Société de Nancy.* 1850, p. 810. On Iron Ores of France.

Lewis, H. C. The Iron Ores and Lignite of the Montgomery County Valley. *Proc. Acad. Nat. Sci. Phil.* 1877-79. pp. 46-55.

Lewis, H. C. The Iron Ores of the Brandon Period. *Proc. Amer. Assoc.* vol. xix., pp. 427, 428, 1880.

———. *Proc. Acad. Nat. Sci. Phil.* 1880. In reference to the supposed remnants of the red sandstone strata discussed by H. D. Rogers, says:

"The iron ores of this region belong probably to four different geological ages, and may, therefore, be divided into four classes.

1. Gneissic Ore. This ore, never found in the (Montgomery Co.) valley, occurs in the gneissic rocks of Chester county north of the Chester Valley, and has been formed in place from the altered gneiss. It dips with the gneiss, and is generally accompanied by scales of graphite. Prof. Rogers supposed that this ore belonged to isolated patches of Triassic red sandstone. The writer, however, has not been able to confirm his sections, nor to show the presence of any more recent formation than the gneiss.

2. Primal ore. The hydromica slates which lie between the Potsdam sandstone and the limestone liberate, when decomposed, a rich limonite ore which is largely mined in portions of the valley. Although in very irregular beds, a steep dip can be recognized. It is perhaps derived from the decomposition of pyrite. This is probably the ore mined at Edge Hill.

3. Tertiary ore. This ore, associated with which are the deposits of lignite, plastic clay, kaolin, firesand, etc., has been hitherto confounded either with the Primal ore or with the drift ore of the valley. In that part of the valley under discussion there are three distinct lines of outcrop of this ore, having nearly an E and W trend. A ridge of limestone separates two of these lines. The ore lies sometimes at a great depth, below a re-stratified, decomposed hydromica slate. This latter formation is almost identical in appearance with the decomposed Primal slate in place at the edges of the valley, and has, therefore, been mistaken for it. The discovery of lignite below it proves its re-stratification in a later age. In many places shafts have been sunk over 100 feet without coming to the limestone. The ore originally derived either from the limestone or from the primal slates, appears to lie below the lignitic strata.

4. Drift ore. Resting often unconformably upon these last, and capping the elevations throughout the valley, is a drift deposit of gravel and boulders, containing a workable iron ore. * * * It appears that there are strong grounds for assigning an upper Tertiary age to the drift ore and gravel of the Montgomery county valley."

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"*Sources of bog iron-ore.* At the bottom of peat masses there is sometimes found a cake, or pan, as it is termed, of oxide of iron, and the frequency of bog iron ore is familiar to the mineralogist. The oak, which is so often dyed black in peat, owes its color to the same metal. From what source the iron is derived has often been a subject of discussion, until the discoveries of Ehrenberg seem at length to have removed the difficulty. He had observed, in the marshes about Berlin, a substance of a deep ochre yellow passing into red, which covered the bottom of the ditches, and which after it had become dry after the evaporation of the water, appeared exactly like oxide of iron. But under the microscope it was found to consist of slender articulated threads or plates, partly siliceous and partly ferruginous, of a plant of simple structure, *Gallionella ferruginea*, of the family called Diatomaceæ. There can be little doubt, therefore, that bog iron-ore consists of an aggregate of millions of these organic bodies invisible to the naked eye."

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"There seems, indeed, to be nothing in these deposits to remove the impression made by the correspondence in position, by the solid bedding occasionally visible, and by the other characteristics of the Smyth County exposures, that the iron ore was deposited in regular beds of greater or less extent and thickness at the same time as the other rocks and that they have been broken into fragments at their outcrops, and that these fragments of hard and heavy ore have accumulated in quantities of various extent according to the lay of the ground, mixed with the loam that comes from the more thorough comminution or decomposition of the other softer rocks and of a portion of the ore itself. * * * * At two or three points in Virginia and Pennsylvania, lumps of carbonate of iron have been found mixed with this brown hematite, and this would go to show that the ore was originally deposited as a carbonate like the coal measure beds of carbonate of iron, and has since been changed into brown hematite either in the solid bed or in the lumps scattered through the loam, a change that so often happens with coal measure carbonates. * * * * The supposition some have entertained that these lumps of ore are derived from the percolation through the loam of water charged with iron dissolved out of the rocks that contained iron in the form of iron pyrites or otherwise, and that the lumps are therefore concretionary in origin, and the result of a segregation so thorough that it sometimes leaves white clay or sand in contact with the ore, has more than one difficulty. The lumps are commonly not of the shape of concretions, for these must be more or less rounded or nodular, as they are formed about centers, and they could never be irregularly angular. * * * * It would seem, rather, as if the effect of the percolation of the water in these deposits had been commonly to give a ferruginous covering and character (taken from the ore) to the materials of the loam when they came from rocks that did not have that character."

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"Magnetic oxide of iron. This ore abounds in Putnam county. Several mines are already wrought and many more are capable of exploration. They form masses in gneiss and hornblende gneiss rocks, which by casual examination would be called beds; but after a careful investigation of the facts, I think they may be called veins. Their course is parallel to the line of bearing of the strata, and they lie parallel to the layers of the rock, but by close examination, it is found that in several instances after continuing with this parallelism for a certain distance, the ore crosses a stratum of rock, and then resumes its parallelism, then crosses, obliquely, another, and so on. In other places where a great bed of the ore occurs at some depth, only a few small strips of ore penetrate through the super-incumbent mass to the surface, as if the rocks had been cracked asunder, and these small seams of ore had been forced up from the main mass below."

On page 111 he says: "On Simewog hill, one-fourth of a mile south, the vein is from 3 to 20 feet thick, associated with similar rocks (gneiss and hornblende gneiss) and with granite. It has been wrought on Simewog hill from 30 to 60 feet or more in depth over a length of 300 to 400 yards. It is scarcely doubted, from the observations made, that this vein is at least two miles in length, with an average width of 6 feet. Its depth cannot be estimated, but it is presumed that the labor of ages could not exhaust it in depth, as the bottoms of such veins have never, in any country, been found."

"The Cold Spring and Patterson turnpike crosses this (Phillips) vein of iron ore near the crest of the mountain, about nine miles from Cold Spring landing. There is an opening near the road, and near this crossing, where some ore has been dug. Here the ore seems injected in little sheets, veins and beds through the gneiss rock, so as to form one-fourth to three-fourths of its mass through a horizontal thickness (as the strata are vertical) of 30 to 35 feet." p. 112. "About three-fourths of a mile S. W. of this is the Denney mine. The ore seems to have been injected among the rocks.

Most of the ore is very compact and pure, but some contains hornblende. Much of the feldspathic rock contiguous to the vein is injected with thin veins of ore from one-eighth to one inch thick." "Contiguous to this opening is another 30 feet deep to the water, with a sheet of rock 5 or 6 feet thick, between two divisions of the vein. The rocks on each side of the vein are more or less injected with thin veins of ore; from examining the locality, many suppose that the ore has been injected into the cracks and crevices of the rock when broken up by some upheave." p. 114. Foot note. "The phenomena of the mines in many places induce the idea of igneous injection, connected with a powerful upheaving force. The feldspar is often pearly, wrinkled, and with few laminae. The appearance of hyalite, a mineral usually associated with volcanic and trap rocks; the apparent injection in thin veins among the seams and crevices of the rock; the appearance of the softening of the gneiss and bending its layers like a flowing slag, seem to point to an igneous origin of this vein. It often has the appearance of a bed, and at other times of a vein ramifying from a main mass between the strata, and at other times cutting obliquely across them, but still having its outcrops parallel to the line of bearing."

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"The direct solvent action of humic, ulmic, and other acids, the product of organic decomposition, appears a more probable agent of dissolution, and does not necessarily involve the reduction of the sesquioxide to the protoxide. According to Bischof (Chemical and Physical Geology, English edition, vol. 1, p. 166) humic acid occurring in vegetable mould forms a compound with sesquioxide of iron soluble in 2500 parts of water, and erenic acid a combination soluble. The formation of limonite or bog-iron ore appears to be the result of such dissolution; it consists of sesquioxide of iron in combination with variable amounts of humic acid (Dana's System of Mineralogy, p. 78, fifth edition). The aggregation of sesquioxide of iron around roots may thus be incidental to its temporary dissolution by the acids of organic decomposition."

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"When on the spot it seemed to us possible to account for the appearance presented by this metallic accumulation, most of which is now but little solidified, either by supposing it to be of plutonic origin, and that, issuing from fissures on the hillside, it had flowed, when in a molten state, into the hollow where it lies, or that it was formerly a mass of sedimentary materials which had been altered and mineralized by heat and vapours, which, making use of parts of the surrounding limestone as a flux, had elaborated this metallic substance. * * * *

We have no hesitation in agreeing with our skillful cotemporary (Helmersen) who has so closely studied the rocks of Blagodats, that these great masses of iron ore have flowed into this depression from fissures in the adjacent hill, and that they have since been cut through by other dykes of similar matter. In our description of the Katchkanar we shall advance independent proof of the igneous origin of magnetic iron."

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"On lake Superior it is now easy to see that the beds were once horizontal strata, deposited in conformity with many other stratified sediments, but they are folded and broken in such a way that their true nature was for a long while misunderstood. Like the magnetic ores of the Alleghany belt, they were once considered eruptive; but the progress of modern science has shown that all the so-called Eozoic iron ores are simply metamorphosed strata, once deposited horizontally like the sheets of iron ore now found in the unchanged Palæozoic rocks,—such as the Clinton ore and the 'black-band' and 'clay-ironstone' of the coal measures."

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Speaking of the ores of the Laurentian and Huronian, says:

"These deposits of iron ore, which are frequently of enormous size, were once universally and are now exceptionally regarded as eruptive in character; but we shall endeavor to show that they are all of sedimentary origin. The arguments in favor of this view are both negative and positive. First as has been stated, we have never found in any quarter of the globe masses of iron ore among the products of volcanic eruption, nor any disconnected with either metamorphosed or unchanged sedimentary rocks." He further says that the highest authorities in chemical geology are "agreed in regarding the deposits of ore which date back to more or less remote geological times, such as the hematites and magnetites of the Paleozoic and Archæan systems, as the effects of similar processes of accumulation (by the reducing action of organic matter upon ferric oxides, thus rendering them soluble, Ed.) subsequently changed physically and chemically by the agents which have metamorphosed the associated rocks. Although we cannot correctly class iron among the organic deposits,—since but little of it has formed part of plant or animal tissue—organic matter is so distinctly a link in the chain of causes and effects by which accumulations of iron have been produced, that we are compelled to regard all iron ore deposits as the results of organic forces, and proof of the presence of animal or vegetable life as an accompaniment of their formation. Hence in the Laurentian and Huronian formations, formerly designated as the Azoic or lifeless rocks, where some of the greatest iron ore beds occur, the iron may be accepted as evidence of abundant life at the epoch of its deposition."

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"Mr. R. W. Fox, after having ascertained the existence of electric currents in many of the metalliferous veins of Cornwall, suggested the probability of this force having acted on various metallic chlorides and sulphides dissolved in the waters traversing vein fissures in such a way as to determine the mode of the distribution of the ores therein. He also endeavored to account for the prevalence of an easterly and westerly direction in the principal lodes of Cornwall by their position in relation to the earth's magnetism.

Weighty objections to this theory have, however, been pointed out by W. J. Henwood and others, and observed facts appear to indicate that the general direction of veins differs so entirely in different mining districts that their course probably depends rather on lines of fracture produced by plutonic, volcanic or other agencies, than on the action of electric currents."

Under the head of "Deposits resulting from chemical action", Phillips (l. c. p. 14) puts the Bog and Lake ores of iron, and says: "In all cases it is the result of the alteration of other mineral substances containing iron when acted upon by air, moisture or acids, and is, to a large extent, due to the oxidation of the pyrites, and to the action of carbonic acid upon siderite, etc. The decomposition of various ferruginous minerals, such as mica, augite and hornblende, also contributes largely to the formation of ores of this class. * * * * * Attention was first called by Kindler to the importance of the effects produced by decaying vegetable matter on the solubility of ferric hydrates. (POGGENDORFF'S *Annalen der Physik und Chemie*, vol. xxxvii. 1836. p. 203.) He observed that where pine trees had been planted upon sand-hills in such a position that falls of sand were occasioned by the action of running water, the ferruginous and quartzose sand was rendered colourless around decaying roots, and that it became in the course of a few months as white as if it had been treated with an acid. The action of a root one-sixth of an inch in diameter, whitens the sand to a distance of from one to two inches around it."

On p. 396 of Phillips' Treatise on Ore Deposits is more upon the subject of Lake ores: "Stapf is of the opinion (F. M. STAPF, *Zeit. d. d. Geol. Gesellsch.* vol. xviii, 1866, p. 86) that lake iron ore is formed in the same way as bog iron ore, and he points out that in the lake of Tisken near Falun, the water from the mine and from the slag heaps has deposited a bed of ochre extending over the entire bottom of the lake within a period of 600 years; this bed is in places above ten feet in thickness. Lake ores when first collected are blackish-gray, brownish, or greenish ochre-like slimes; on hardening, however, little globular masses analogous to those of oolitic iron ore are often formed.

Ehrenberg (1836) first suggested that these ores are produced by certain infusoria, which build cells mainly composed of hydrated oxide of iron. The *Gaillonella ferruginea* is especially an industrious manufacturer, of iron ore by secretion from dilute iron solutions."

As to the manner of occurrence of limonite, Mr. Phillips says, (p. 404) with particular reference to the deposits in the Ural: "Brown hematite deposits occur under very varying conditions, namely:

1. In small irregular masses in plutonic rocks.
2. As beds in metamorphic rocks.
3. In beds at the contact of the metamorphic rocks with Silurian limestones.
4. In deposits at the contact of metamorphic and plutonic rocks.
5. In accumulations in the lower horizons of the Silurian formation.
6. In beds in clayey sandstone of Carboniferous or Devonian age.
7. As accumulations in the form of nests in Silurian or Carboniferous.
8. As accumulations in alluvium."

Mr. Phillips speaks of beds and veins or lodes of magnetite in various places. On p. 437: "In Peninsular India the magnetic oxide occurs either in beds or veins in almost every region in which metamorphic rocks prevail. . . . In many cases these deposits would appear not to be in the form of veins, but to occur as beds, in the same way as do the gneissoid and schistose rocks with which they are associated. Bedded magnetite is likewise known to occur in the sub-metamorphic or transition rocks; while, both in the metamorphic and sub-metamorphic series, considerable veins of limonite are found in fissures and along lines of fault."

On p. 248 is the following statement: "The iron deposits of Rancié (France) occur in nearly vertical beds, one of which is so permeated by brown and red hematite, spathose iron ore, and occasionally with oxide of manganese, that ore frequently becomes the prevailing material. The limestones are often much colored by oxide of iron, and are traversed by numerous veins of pure hematite containing druses lined with concentric layers of brown and red oxide of iron. This bed, which has an average thickness of about six y-five feet, can be traced from the bottom of the mountain to its summit, a height of 1,970 feet, while its inferior limit has never yet been reached. The parallelism of this formation with the surrounding strata caused them for a long time

to be regarded as being of contemporary origin, but M. Dufrénoy, who some years since examined this deposit, inclined to the opinion that the deposition of iron ores took place subsequently to that of the enclosing strata."

In reference to the deposits of hematite which in England fill cavities, and hollows in the Carboniferous, Mr. Phillips says (p. 164) that it seems probable that it was "originally deposited in the form of carbonate of iron. It will be easy to conceive that, on a solution of this substance in water containing carbonic acid coming in contact with limestone, the carbonate of iron would be deposited, and its place in the solution occupied by carbonate of lime. When the carbonate of iron had been thus formed, its change into hematite was probably effected by a process somewhat analogous to that by which siderite is so often seen to become converted into brown iron ore. That a portion at least of the hematite has replaced carbonate of lime becomes evident from the fact that numerous fossils of the Carboniferous limestone have been found in the ore, and that some of them have only been partially converted into oxide of iron.

It is somewhat difficult to conceive whence the iron forming such numerous ferruginous deposits could have been derived, but Mr. Kendall suggests the coal-measures as the probable source from which this metal originally came. He further remarks that it is well known that the sandstones and shales belonging to this formation contain a large percentage of iron; and as these rocks at one time probably overlaid the Carboniferous limestones of the hematite producing districts, he thinks it not improbable that a large proportion of the iron in the limestones may be the result of the percolation of waters charged with carbonic acid gas, through superincumbent beds which have been since removed by denudation."

Speaking of the lake Superior district Mr. Phillips says, p. 580, 581: "The iron-bearing rocks of lake Superior correspond to the Huronian system of Canada, and consist of a series of extensively folded beds of diorite, quartzite, chloritic schists, clay slates, mica schists, and graphitic shales, among which are intercalated extensive beds of several varieties of iron ore." The same authority also says, p. 582: "The principal deposit of spathic iron ore in the United States is at Roxbury, Connecticut, where, in association with quartz, it occurs in a vein traversing gneiss."

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Platt, F. Report 2nd Penn. Survey. L. pp. 98-116. 1876.

Playfair, John. Illustrations of the Huttonian Theory of the Earth. *Edinburgh.* 1802.

"The materials which fill mineral veins were melted by heat and forcibly injected, in that state, into the clefts and fissures of the strata. These fissures we must conceive to have arisen, not merely from the shrinking of the strata while they acquired hardness and solidity, but from the violence done to them when they were heaved up, and elevated in the manner which has already been explained." p. 61. "The large specimens of native iron found in Siberia and Peru, mentioned above, § 51, are among the most curious facts in the natural history of metals. * * * The metal is too perfect, and the masses too large, to have been melted in the furnaces or to have been transported by the machinery, of a rude people. The specimen in South America weighs 300 quintals, or about 15 tons, and is soft and malleable. (*Phil. Trans.* 1788, pp. 37, 183). The Siberian specimen, described by Pallas, is also very large; it is soft and malleable, and full of round cavities, containing a substance which, on examination, has been found to be chrysolite. Now it is certainly quite impossible that, in an artificial fusion, so much chrysolite could have come by any means to be involved in the iron; but, if the fusion was natural, and happened in a mineral vein, the iron and chrysolite were both in their native place, and their meeting together has nothing in it that is inexplicable." p. 239.

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valuable description of the iron ores and mines of Missouri in 1884. Contains many analyses and facts of interest.

Pouyanne, —. [Iron districts of Quelhassa.] *Ann. Mines*, sér. 7, t. ix, p. 81. 1876.

Preaubert, F. [Ancient Iron Mines and Silurian Rocks of Angers.] *Bull. Soc. Etud. Sci. Angers*. 1876-77, pp. 15, 2 pls.

Prime, F. Jr. Limonite Deposits of the Great Valley. *Am. Jour. Sci.* (ii) vol. ix, No. 54, p. 437, 1875. *Trans. Am. Inst. Eng.* 1875.

"I have shown in the commencement of this paper that they (the strata containing the brown hematite deposits and assigned by Hunt to the Huronian) are *Calciferous* slates or schists: and were the ores formed by the alteration of pyrites *in situ*, we should find kernels of iron-pyrite which had escaped alteration, especially in the deepest mines. This is not, however, the case. * * * Prof. Lesley, (Report on the Brown Hematite deposits of the Nittany Valley) thinks the ores "were deposits *in loco originali* of the iron (as hydrated peroxide) set free from the limestone or dolomitic rocks during their gradual erosion and dissolution," agreeing in this respect with Dr. R. M. S. Jackson, who made the first geological survey of the Nittany valley ore beds in 1838 or 1839. * * * The brown hematites were probably formed by the oxidation of iron pyrites, but the former are not in the same place that the latter were. My reasons for this assertion are two-fold. In the first place, the animal carbon of the organisms, whose shells formed the enormous quantity of dolomite or limestone, exists in such quantities throughout the limestone as to color the rock, the zinc blende (of Friedensville) and the carbonate of iron a bluish-grey. This same carbon would readily reduce the sulphate of iron carried into the ocean to iron pyrites. As a proof of this reduction I have only to mention that iron pyrite has been found in the mud of a pond.* Secondly, the great majority of the brown hematites which I have had analyzed, and they are many, contain a *trace* of sulphur usually not more than a few hundredths of a per cent. I have also found minute (almost microscopic) crystals of iron pyrite in much of the limestone where it is opened in quarries, and I have also seen in much of this same limestone, where weathered, minute cavities, which I have ascribed (perhaps erroneously) from their general appearance, to the decomposition of the pyrite. * * * My objection to the original deposition of the carbonate of iron, as such, in the Carboniferous epoch is three-fold. In the first place it should be uniformly distributed through the limestone and not confined merely to the horizon just above the damourite slates. Then there should not be even the trace (the few hundredths of a per cent) of sulphur in the brown hematites, which we so uniformly find. And finally there seems to be a lack of cause, such as exists in the case of the carbonates of lime and magnesia. For these were secreted by the marine animals to form their shells, etc., which would not be the case with the carbonate of iron.

"In conclusion, I would once more point to the fact that, whatever the origin of brown hematites may have been, the cause of their deposition, where they are now found, must have been the damourite slates."

— 2nd Geol. Sur. Penn. Report of Prog., 1875, DD., p. 52.
Speaking of the origin of the Brown Hematites, says:

"The ore must then have been formed either from the decomposition of ferrous salts *in situ* (i. e., ferrous silicates or the carbonate), from the solution of the ferrous carbonate in the limestone and its redeposition in the damourite slates, or from the same reaction of the ferrous sulphate formed by the oxidation of pyrite. The presence of large quantities of quartz, forming strings and bands, associated with the brown hematite ores in the damourite slates, tends to show that a very large proportion of the iron has been originally deposited as a silicate, this being subsequently decomposed by the action of percolating waters containing air and carbonic acid in solution. On the other hand, the presence of carbonate of iron, as found at Barber's Mine, formerly also at Ironton and in the Saucon valley, would indicate that a portion of the brown hematite had either been originally deposited in the slates as carbonate of iron, or that by some reaction at present obscure (possibly the reaction of some potash salt), the carbonate had been formed and deposited, and by subsequent oxidation converted to the hydrate. Finally the ferrous sulphate formed by oxidation of pyrite would react on any alkaline silicates present, and converting these into sulphates would itself be thrown down." In regard to the time at which this deposition took place, he says (i. c. p. 76): "The conviction has been rather forced upon the writer, that we have to distinguish two periods (of glacial deposition, Ed.) The one when the glaciers, coming through the gaps of the Kittatinny mountain, and in places riding over its crest, came down to the South Mountain, bringing large quantities of detached rocks with them, excavating the slates and limestones in their course, and depositing in the limestone excavations thus made, clay, sand, boulders and brown hematite. In this manner were probably formed those sporadic brown hematite deposits which we find scattered along the middle of the limestone valley, and which are so uncertain, both in their extent and quality. The second period is that of the retreating glaciers."

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Pumpelly, R. *Geol. Sur. Mo.* Preliminary Report on Iron Ores. p. 8, *et. seq.* 1872.

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"Both the Archæan crystalline rocks and the Silurian strata have undergone immense changes in volume, and in other respects, under this long continued influence. The gradual removal of the soluble constituents has left important residuary deposits of such substances as were insoluble, especially in the Silurian strata, as clay, flint, crystallized quartz, sulphuret of iron, galena, etc. The more conspicuous instances of this kind among the pre-Silurian rocks are residuary occurrences of iron ore.

The formation of residuary deposits of iron ore, having their origin in the gradual removal of very resisting crystalline rocks, is one of the local results of this weathering away and decomposition of the rock, and is well illustrated in the surface ore at Iron Mountain." (pp. 9, 10, loc. cit.)

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The ore occurs in a massive labrador-stone, sometimes in vein-like streaks and pure.

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"The origin of the deposits of bog ore of the region before us (The Tertiary) we can readily understand by adverting to the very ferruginous nature of nearly all the strata, both the green sand and the beds overlying it. The water, not only in the marl region proper, but throughout the adjacent tracts, contains very generally a considerable quantity of the oxide of iron, which it procures in its passage through the upper strata. Upon coming into the open air it parts with the carbonic acid, the agent by which it is enabled to retain the oxide of iron in the dissolved state; this it quickly precipitates, and hence the accumulations of bog ore in all situations where the low grounds are entered by springs passing out of the more ferruginous beds of sand and clay." (Rep. Geol. N. J. 1868, p. 665.)

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"But the most conclusive proof of undulations in the gneiss, and one which accounts for the presence of these deposits of iron ore, is the occurrence at almost every dislocation of an insulated patch of the Mesozoic red sandstone. The iron ore usually rests in a cleft or deep narrow trough, confined between steeply dipping beds of gneiss, or a wall of granite on the one side, and moderately steep southeast dipping strata of the red sandstone, within or behind which no ore is ever found, on the other." "We may account for the existence of the outlying narrow belt of the red sandstone, and for the presence of the deep and rich deposits of hematite iron ore which they contain, and which have evidently been derived by percolation from their strata, by the long continued trickling of the surface water in the line of fracture." In reference to another series of iron ore deposits, he says: "I would not, however, here wish to intimate that either of these two last mentioned deposits can be recognized as occupying the line of fault in the strata in which we recognize the iron ore. It seems probable, indeed, that the western deposit is not connected with any synclinal trough in the rocks, but is the result of an extensive decomposition of very ferruginous beds of gneiss. Possibly, however, this part of the valley, like that at the Lewis mine, may once have been overspread by a narrow, thin capping of ferruginous red shale and red sandstone (of Mesozoic age.)"

Speaking of the ore deposits found in troughs of the gneiss as a whole, he says in the same place: "A careful inspection of the ore and all the attendant phenomena disclosed in these excavations, cannot fail to suggest the notion, that the (Mesozoic) red sandstone is the source of the iron ore, and that it has yielded it up by a process of filtration, and percolation of the surface waters, by which it has been carried down into the cleft between the rocks, and left there to concrete."

Further on he speaks of the iron ore resting upon the red sandstone instead of under it. "In the Latschaw mine, the stratum of red sandstone seems to have been caught in a deep fracture in the gneiss, and greatly squeezed and crushed. The iron ore reposes on the slanting face of this compressed mass of sandstone and of shale, and is even dispersed or mingled through its fragmentary materials along the line of the fault. So crystalline is the red shale and sandstone, and so full of scales of segregated mica and plumbago, that the observer is sometimes at a loss to decide, from hand specimens, whether the rock is really an altered sandstone or a variety of gneiss."

At this pit (Jones' mine) there seems to be a line of fault in the strata, filled with fragments of gneiss, of intrusive white granite, and of highly altered crystalline red sandstone. The iron ore, in a crude and sandy state, is interspersed through this confused mass, which it serves more or less to cement. On the south side of the trench containing the ore, we meet, as usual, with steep strata of gneiss, and on the north side with southeast dipping beds of a rock which, from its highly crystalline condition, and its abounding in mica and in specular iron ore, greatly puzzles the observer to determine whether it also is gneiss, or a highly metamorphosed form of the argillaceous red sandstone."

Rogers, H. D. *Geol. Penn.*, vol. ii, p. 713, *et. seq.* 1858.

"The magnetic iron ore occurs only in the form of true veins of injection or genuine mineral lodes. Its veins very generally coincide approximately in direction and inclination with the crystalline strata, between the layers of which they lie, yet this conformity is only partial, for when they are traced with close attention they are occasionally found to intersect the strata for a short distance, and then resume their parallelism. These iron ores evidently reached the positions in which we thus find them while in a melted state, their intrusion being the result of an enormous subterranean force, rupturing the earth's crust in the direction of the strata, or in the planes of weakest cohesion, and pressing the liquid ore and other fused mineral matters into the open fissures. Where the rent has been at all irregular or splintery the vein which filled it is interrupted or uneven, being in some places pinched to very narrow dimensions by the approximation of its walls, in others dilating by their recession, and in many cases being split into two or more parallel branches by the insertion of a wedge-shaped portion of one or other wall.

The oxide of iron, while the whole mass of the vein was yet in a state of fusion and very fluid, would necessarily, from its greater relative weight, follow the lower wall of the fissure as it flowed to the surface, while the much lighter earthy minerals would float, as it were, upon the upper side of the ore, taking the position, with respect to the latter, of its scoria or cinder. This would arise wherever the slope of the fissure was sufficient to give the force of gravity much control in the distribution of the materials; but in all cases of a perpendicular vein there would be no tendency in the heavier metallic portion to collect on one side rather than on another, and therefore it and the lighter mass would mingle more conspicuously.

There are many veins which are not accompanied by any separate body of granitic matter, but contain the felspar, hornblende or other minerals in much abundance, disseminated through the ore. These we may imagine to have acquired their solid state, at least in portions near the surface, where alone we can observe them, from a condition of imperfect fluidity, like that of the already half-chilled lava of some volcanic eruptions, which would effectually prevent the separation of the heavier from the lighter constituents." On page 716 he says in speaking of "Penn's Mount Ore-vein":

"In the district we are now describing, though not strictly within the gneiss itself, there is an important vein of igneous iron-ore, which has been wrought for some years. It is opened on Penn's Mount, about half a mile east of Reading.

"The vein apparently is injected conformably to the bedding of the primal white sandstone, and the ore is not accompanied by any bounding wall of igneous rock, but is in immediate contact with the sandstone itself. The latter rock disintegrates quickly on exposure to the atmosphere, and develops innumerable small grains of hornblende, which speckle the yellowish-grey sand. The ore-vein ranges from Reading Fair ground, a little south of east, dipping 45 degrees south. Its thickness is seldom less than 18 inches, and has been as great as 28 feet. Under this enlargement it does not appear to suffer in quality. The ore itself is of the granitoid variety, highly crystalline, containing quartz and felspar, especially the latter, in great abundance: hornblende and apatite enter also into its composition."

Regarding the origin of the surface iron ores of the Primal series, Rogers says, p. 721:

"Respecting the ultimate source of the oxides of iron and manganese, it is to be sought in the ferruginous slates upon which the deposits repose. The loamy soil imbedding the ore appears to have been derived from the disintegration of the slate previously collected in a fragmentary or even pulverized condition in the depressions of the surface. Under the action of the percolating rain and springs, these materials would be converted into a mere loam, and the oxide of iron set free. Much of the iron has been originally in the condition of the sulphuret of iron, diffused in minute crystals through certain layers of the slate. The facility with which this mineral undergoes decomposition, and gives rise to hydrated peroxide of iron upon the access of atmospheric air and the rain water, is a fact familiar to chemists. This view of the origin of a part, at least, of the ore, accords with what is known concerning those slaty rocks which contain much sulphuret of iron.

"These regularly-bedded ores of the Surgent series are to be regarded as among the permanent constituent strata of the formation, and as having originated, with the other sedimentary materials, in the form of very extended but thin sheets of ferruginous matter, covering at successive epochs the wide floor of the quiet Appalachian sea. Whence all the oxide of iron was derived which mingled with the earthy deposits of clay, sand, carbonate of lime, and the fossils of these deposits, is a question which the present state of research scarcely enables us to answer. Perhaps we are authorized from a consideration of the physical changes which seem to have occurred at the close of the Matinal period, to refer its origin to a wide expanse of newly-upraised land of Primal and Matinal sediments, impregnated with a certain proportion of ferruginous matter, and to suppose that these parts, freshly exposed to active erosion and waste by atmospheric agents, in supplying a part, at least, of the materials of the Surgent strata, contributed, by steady accumulation, a copious amount of the salts of iron in solution to the waters of the Levant ocean. We have only to imagine, in the next place, the operation of certain well known chemical reactions, such, especially, as would arise upon the sudden introduction of calcareous matter, to perceive a sufficient cause for the extensive precipitation of a definite quantity of the iron in the form of the peroxide.

"This explanation derives some countenance from the independent evidence afforded,—by the more calcareous and fossiliferous nature of these ore-beds, compared with the strata which embrace them,—that the epochs of the deposition of the iron ore were also the periods of the most copious supply of carbonate of lime.

"To this source we may ascribe, with some probability perhaps, a large portion of the peroxide of iron in these layers; but we must not overlook another train of causes, operating since the elevation of the strata, to contribute in certain situations an increased supply of this ingredient. An enormous quantity of ferruginous matter, both in the shape of the sulphuret and peroxide of iron, is diffused through the substance of

the slates, shales and marls in contact with these layers of ore, and the infiltrating waters have probably conveyed some of this, chiefly in the condition of sulphate of iron, into the ore-bed, where the carbonate of lime of the fossils would convert it into the peroxide. That such has been the origin of a part of the iron in the "fossiliferous ore" of some localities, is indicated by the general richness of the ore in peroxide, in all situations where the position of the outcrop, the slope of the ground, and the thickness of the covering slate, are favorable to a copious infiltration of the surface-water," (l. c. p. 729).

Rogers, W. B. On the Origin and Accumulation of Proto-carbonate of Iron in the Coal Measures generally. *Annual of Sci. Disc.* 1857, pp. 314-318.

The carbonate of iron was produced by the reducing action of organic matter, undergoing changes when in contact with it *in situ* in the rocks, and not in solution.

——. *Geol. Penn.*, ii, pt. ii, pp. 722, 729, 737. 1868.

Rogers, E. Iron Ores of South Wales. *Mem. Geol. Sur. Iron Ores of Great Britain*, part iii, 8vo., p. 91. 1861.

Rohde, J. G. On the Non-Meteoritic Origin of the Masses of Metallic iron in the Basalt of Disko, in Greenland. Selected and translated from the original Danish paper of K. J. V. Steenstrup. *Min. Mag.*, vol. i, no. v, p. 143.

"Gives objections to assigning a meteoric origin for these iron masses, from the mode in which they occur in the rock. Describes the basalt, and shows from examination of a basalt from Assuk, on the Waigat, that native iron does sometimes occur in basalt." (*Geological Record*, 1878.)

Rominger, C. Geological Survey of Michigan, Upper Peninsula, 1878-80. Vol. iv, pt. 1, Marquette Iron Region; pt. 2, Menominee Iron Region, 8vo. New York. *Geol. Map*, 1881.

Rössler, B. Speculum metallurgiæ politissimum, oder hellpolierter Bergbauspiegel. *Dresden*. 1700.

Roth, Justus. Allgemeine und Chemische Geologie.

Rothwell, Richard P. Alabama Coal and Iron. *Trans. Amer. Inst. Min. Eng.*, vol. ii, pp. 144-158. Also *Coll. Guard.*, vol. xxx, pp. 131, 132, 386. 1875.

Rottermund, Count de. Report on the Exploration of Lakes Superior and Huron. Canada Legislative Assembly, 1856, 24 pp.; *Canad. Jour.*, 1856, (2), i, 446-452.

Royal Commission (Ontario). Report on the mineral resources of Ontario, and measures for their development. Roy. octavo, pp. 566. *Geol.*, map and illustrations, Toronto, 1890. The Commission consisted of **John Charlton**, (Chairman), **Robert Bell**, **William Coe**, **William H. Merritt** and **Archibald Blue**.

Ruffner, W. H. Report on the Landed Property of the Buena Vista Company. *Philadelphia*. 1889.

On page 23 Mr. Ruffner says: "The only material difference of opinion among geologists as to the origin of the ores found in the slates is as to whether they were originally deposited from solution in separate beds on the surface of the slates, whilst they still lay undisturbed on the bottom of the Potsdam ocean, or whether they were diffused chemically or mechanically through the mass of slaty material like other elements, and subsequently gathered into beds after the sea-bottom was lifted into the air. According to the latter view, which is the more common, this aggregation of the particles of iron oxide was made possible by the decomposition of the whole body of slates. The slates originally contained large proportions of lime, potash and soda, all of which are soluble in acidulated waters. As these elements were leached out and the slates gradually converted into clay, it is thought that the iron was dissolved out by the same waters and deposited in beds or pockets when reaching some impervious layers or basins of clay. Neither this theory of the genesis of the ores nor any other that I have seen, reconciles all the facts."

Russell, I. C. Subaërial decay of rocks, and origin of the red color of certain formations. *U. S. Geol. Survey; Bulletin*, No. 52, pp. 22-23. 1889. Regards the red color as due to residual clay and ferric oxide from the decay of the older rocks, drained from the land into the ocean at the time the red beds were being accumulated. Applies this theory particularly to the Newark system, and the Red Beds of the central part of North America; but does not apply it to the associated iron ores, indeed does not mention the iron ores, the existence of which seems to furnish an extreme instance of the same phenomena, whatever may be the cause.

Ruttmann, Ferdinand S. Notes on the Geology of the Tilly Foster Iron Mine. *Trans. Am. Inst. Min. Eng.*, xv, pp. 79-90.

Safford, J. M. Geol. Reconnaissance of Tennessee, 1856. Mentions iron ores in various localities, and in speaking of the "Western Iron Region," p. 49, says:

"We are inclined to think that the ferruginous chert of this limestone has been the great source of the peroxyd of the ores. Liberated by its decomposition the iron oxyd, in some form or other, has permeated the loose leached masses, and has been finally left in the beds, veins, pots, pipes, etc., in which we now find it."

———. Geology of Tennessee, 1869. Refers to iron ores in many places in this volume, and though no particular chapter is devoted to a discussion of their origin, it is evident that he considers them to be the results of decomposition, oxidation and segregation, or of ordinary mechanical sedimentation. On p. 210 we read:

"In Carter county, seven miles above Elizabethton, on the west side of Stony creek, is a layer of massive hematite, from one to two feet in thickness. The locality is known as the Cannon bank. The iron ore is regularly stratified, rests on a thin bed of conglomerate holding small pebbles, and has sandy shales above."

"At another locality, Sharp's bank, in Sullivan county, it occurs in a vein-like, nearly vertical mass. This mass of ore is associated with light gray dolomite, of the uppermost part of the Knox group. The rocks dip at a high angle. The hematite most likely dips with them, not being a true vein intersecting the strata." (p. 222, l. c.)

"I have been much inclined to think that the principal and original source of the ore (limonite, p. 350) has been the ferruginous chert of the Lithostrotion bed. It has iron enough to color the soil characteristically red. The banks are centres at which, through the agency of chalybeate waters drawing their iron from the decomposing chert, the ore has accumulated." And again, p. 451: "It is an interesting fact pointing to the origin of the limonite in these banks that localities are not within the coves in which the banks occur, where the limestones and dolomites contain disseminated grains of *pyrite*, *blende* and *galena* (*galenite*). Such is the case in Bompas cove, and at one point the galena is so abundant as to have attracted notice as a 'lead mine.' We are led to infer from such facts that the limonite of the overbank, at another point in this cove, and the lead and zinc ores associated with it, are oxydized portions of the leached remains of limestone, which, like those above, originally contained pyrite, blende and galena."

Salter, J. W. Ironstones of the "North Crop." *Mem. Geol. Sur. Iron Ores of Great Britain*, pp. 219-236. 1862.

"The carbonic acid generated by decomposition of the plants would readily unite as a bi-carbonate, with whatever iron were present in the water, and be precipitated, as a carbonate of iron, in the form of 'Ironstone'."

Sandberger, F. Untersuchungen über Erzgänge. Heft, i. 8vo. Wiesbaden. Pp. 159. Ore-deposits and veins of Schapbach, Black Forest, 7. 1882. Abstracted in *Eng. Min. Jour.* March 7, 15, 22, 29, 1884, under the title "Theories of the Formation of Mineral Veins."

Satisfied himself that the heavy metals occur in the silicates of crystalline rocks of every geological age.

———. *Neues Jahrb. f. Mineral.* 1867, p. 175.

Sanders, George U. Mineral Lands of Lake Superior. Senate Docs., 2nd Sess. 28th Cong., 1844-45; vii., No. 117, pp. 3-9; xi., No. 175, pp. 8-14.

Sauvage, E. Notice sur les minerais de fer du Lac Supérieur. *Ann. Mines.* 7 sér. t. viii. 1875.

Saytzev, A. [Useful Minerals of the Province of Nijny-Novgorod.] *Mat pour l'appréciation des sols du gouv. de Nijny-Novgorod.* Livr. xiii, pp. 1-41 1886.

Scheerer, ———. *Leonhard's Jahrb.* 1843. p. 631. Iron Ores of Arendal, Norway.

Schelle, C. J. van. [Occurrence of Ores of Iron and Copper near Panigahan, Sumatra.] *Jahrb. Mij. Ned. O.—Ind.* vol. 1, p. 3. 1877.

Schmidt, A. R. *Berg. u. Hüttenm. Zeitung.* 1865. pp. 30, 31.

Schmidt, Adolph. Geology of Missouri, p. 94. 1872.

"The deposits of specular ore in the porphyries of eastern Missouri, especially in St. Francois and Iron counties, occur in the most varied sizes and shapes. There are very large deposits side by side with those scarcely workable. There are regular veins, as in Shepherd Mountain and Iron Mountain; there are regular beds, as in Pilot Knob and in some localities east of it; there are irregular deposits, some of which approach

veins by their shape, as on Lewis Mountain, while others have proved to be isolated pockets, as on Hogan Mountain."

"1. It seems to me in the first place, that these deposits of specular ore, being all of a very similar mineralogical character, being all associated with the same kind of rock, and all situated within a small area of territory, must have been produced by one and the same kind of geological action, although the chemical action may have been different in different localities. * * * The description of the various deposits which I shall give hereafter, will show the impossibility of supposing that the ores were injected in a melted condition. There is no sign of the action of very high heat on the associated rocks. All the inclosures found in the veins and beds of ore are of such a character that they would combine and melt in a very short time, when in contact with such large masses of melted ore. The ore is found in very thin fissures, of such an extent that a force capable of filling them with melted ore would certainly have opened the fissures, and would have produced thicker veins. Smelted and chilled ore has a very different appearance from that existing in these deposits.

2. A distillation could rather be thought possible. But distillations of iron-salts occur only in volcanoes, and are there mixed with other distilled matters, and never form large deposits. Here, on the contrary, the deposits are very extensive, the ore very pure, and neither lavas nor any other volcanic rocks are found in the ore region, nor does the configuration of the ground indicate the former presence of any kind of volcanic action.

3. These specular-ore deposits cannot be derived from segregation, by waters penetrating the adjacent porphyries, dissolving iron out of their mass, and depositing it in the fissures; for such an action would have altered these porphyries uniformly along the veins and beds, which is not found to be the case. Such segregation could, besides, hardly have produced such immense deposits as Iron Mountain and Pilot Knob, and would certainly have caused a less uniform structure and frequently stalactitic forms.

4. The specular-ore deposits of eastern Missouri, therefore, must all have been formed by infiltration and precipitation from chalybeate or iron-bearing waters, similar to those which occur still in all parts of the world in the form of chalybeate springs, and are now forming ore deposits in numerous localities.

"All rocks of which the earth is composed are more or less penetrated by water; all are more or less broken or permeated by wide or narrow cracks and fissures; nearly all of them contain iron, some in very small, others in larger quantities. The iron can be dissolved and extracted from these rocks by certain solutions at certain temperatures. From the bottom of the sea, of the lakes, of the rivers, from the surface of the ground all over, waters continually filtrate into the rocks below. These waters all contain more or less carbonic acid and other substances which they take up from the atmospheric air and from the soil. As they descend they dissolve various other matters under various circumstances, from the rocks through which they flow. They follow the easiest and widest channels. They grow warm, and sometimes hot, partly by the natural warmth of the rocks, partly through the heat produced by chemical reactions. The higher temperature and the higher pressure increase their capacity for dissolving mineral matters, with which they become charged as much as the existing circumstances allow. They may contain chlorides, sulphates, silicates, carbonates; they may contain silica, alumina, alkalies, lime; they may contain zinc, lead, iron, etc.

"When these solutions have reached a sufficiently high temperature, and happen to find sufficiently easy channels upward, they will rise through such channels, driven by the pressure of the colder and therefore heavier solutions which follow them, and frequently assisted by the development of gases through chemical reactions. In this course upward they will again follow the preëxisting natural channels, wide fissures, small cracks, irregular holes and pockets. When they reach porous or loose strata, they will penetrate and impregnate them. When they come in contact with strata of materials which they are apt to decompose chemically at the existing temperature, they will alter, transform, metamorphose them. When these materials are such as to precipitate oxides of metals from the solution, these oxides will be precipitated and ore deposits will be formed. The same effect must result when such metallic solutions approach the surface, where their pressure and temperature, and therefore their dissolving capacity is diminished or altered.

"As the circulation of waters and watery solutions just described, although locally variable, has existed during the whole geological history of our globe, as it exists still, it is evident that the largest fissures and cavities, when kept filled with however dilute yet continuously renewed metallic solutions for hundreds and thousands of years, under otherwise favorable conditions, will finally become filled with deposits of ores.

"It also appears evident from the above, that the same mineral solutions can, under different local conditions, produce very different kinds of deposits—veins in one place, pockets in another, beds in a third. I have no doubt that the various deposits of specular ore in porphyry, which I will now proceed to describe, were formed in this wise." (I. c. p. 97.)

Again (I. c. p. 116) he says: "Referring to this deposit (Pilot Knob) specially, I fully agree with Professor Pumpelly, who by more detailed and more thorough investigations, has come exactly to the same conclusion, namely, that it has been formed by a gradual replacement of stratified porphyry by ore, effected by solutions similar to those which deposited the ore in the Iron Mountain and in the other places."

Speaking of specular ore in and on sandstone and limestone, Dr. Schmidt says (I. c. p. 126.): "It seems that these specular ore deposits were originally formed in a lenticular shape, and imbedded in or on a sandstone containing layers of chert, and that they were afterward partially or wholly underwashed, some of the softer sandstone being thus removed, while the harder cherty parts and layers remained. In consequence of this action, a slight shifting of the whole mass of ore may have taken place, which somewhat crushed and mixed some of the underlying materials, and brought the deposit in a more or less inclined position."

Speaking of limonite deposits on limestone he says (I. c. p. 177): "The solutions from which the ore was deposited have been infiltrated from above. The chemical influence

of the carbonate of lime has undoubtedly contributed, in no small extent, to precipitate and deposit the iron in the form of hydrated oxide."

"In some instances large caves, which are so common in all limestones, and which are undoubtedly formed by the dissolving action of acid waters, may have existed in the third magnesian limestone, below the ore-deposits, and may have caused either a gradual or a sudden sinking, without which the origin of the pockets with almost vertical walls, in which such deposits are sometimes found, cannot be easily explained. The original lenticular masses of ore may have been formed either by deposition from chalybeate waters in depressions on the surface of the sandstone, and afterward covered by other strata, and condensed and altered by pressure and higher temperature, or else they may have come into existence by a gradual replacement of lenticular limestone deposits formed in the above-described manner in the sandstone."

Schmidt, Dr. Adolf. Iron Manufacture in Missouri. *Trans. Ac. Sci., St. Louis*, vol. iii, No. 3, pp. 261-272. 1876.

———. *Structur der Spatheisenstein-Lagerstätten bei Neuberg. Oesterr. Zeitschr. Berg- Hütt*, p. 480. 1880.

Schmidt, A. R. *Berg-u Hüttenm. Zeitung*. 1866; p. 69, 97. ——— *ibid.* 1867, p. 401, and 1870, p. 174.

———. Preliminary Notice of the Baltic Iron-ore Deposits. (In Russia.) *Rep. Russ. Geol. Com.*, vol. ii, pp. 107-122; cut. 1883.

Schmidt, — Theorie d. Verschiebungen älterer Gänge. *Frankfurt*. 1810.

Schoolcraft, Henry R. "A view of the Lead Mines of Missouri, etc." *Am. Jour. Sci.* i, iii, 1821, pp. 59-72. *New York*, 1819, 8vo.

———. Narrative Journal of Travels Through the Northwestern Regions of the United States, extending from Detroit through the Great Chain of American Lakes to the Sources of the Mississippi River. *Albany*, 1821, 419 pp., with map.

———. Narrative of an Expedition through the Upper Mississippi to Itasca Lake, the Actual Source of this River. *New York*, 1834, 307 pp. with map. Contains a Report by Douglass Houghton.

Schultz, — *Karsten's Arch.*, 1837, vol. iv, p. 229. Describes deposits of Iron Ores of the Harz.

Scoresby, Rev. William. On the Uniform Permeability of all Known Substances to the Magnetic Influence, etc., pp. 50. 1832.

Seeland, F. [Hüttenberg Iron-ores and their surrounding Rocks.] *Jahrb. k.-k. geol. Reichs.* Bd. xxvi, Heft. 1, pp. 49-112. 1876.

———. [Manganese and Hämatite Mines on the Kok. N. W. of Uggowitz.] *Verh. k.-k. geol. Reichs.* pp. 36-37. 1878.

Senft, Dr. Ferdinand. Die Humus-, Marsch-, Torf- und Limonit-Bildungen als Erzeugungs-Mittel neuer Erdrinde-Lagen. 226 pp., 8vo. 1862. *Leipzig*.

Serlo, Albert. Leitfaden zur Bergbaukunde. *Berlin*. 1878.

Seys, Rev. John. On Native iron in Liberia. *African Repository*, June, 1851. *Annual of Scientific Discovery*. 1856; p. 305.

Shaler, Prof. N. S. The Economic Future of the new South. *Arena*, Vol. 2, No. 3. *Aug.* 1890; p. 267.

"The peculiar ease with which the southern iron ores are mined is in good part due to their geologic conditions. They are generally in the form of true beds which once were limestones, and have been converted by percolating waters containing iron in a dissolved form into iron ores."

Sharples, S. P. Note on Black-band Iron Ore in West Virginia. *Trans. Am. Inst. Min. Eng.*, vol. x, p. 80. 1882.

Shepard, C. U. Report Geol. Sur. Conn., 1837; p. 13, *et seq.* Regards the deposits of ore, both magnetite and limonite, which he has observed in Connecticut, as being in *beds*. In one place he says:

"The ore is included in gneiss and occurs on a low mountain, about one hundred and fifty feet above its base. The position of the bed is nearly vertical, its sides being well defined, and distant four feet." And again: "A more encouraging prospect for obtaining a supply of magnetic iron is afforded in the northwestern corner of Winchester, where a thin stratum of it was discovered upwards of forty years ago. It is contained

in gneiss, and like the two last embraces chlorite." Under *Limonite* he says in reference to some deposits of the ore mentioned previously: "The two first form beds of mica slate; the last in a micaceous gneiss and quartz rock. At Sharon and Salisbury, the ore is disposed in vast beds with a stratification everywhere obvious, and perfectly conformable to that of the adjoining mica-slate."

"The origin of limonite in these rocks (mica slate, micaceous gneiss or quartz rock) may be attributed to the decomposition of the sulphuret of iron and other ferruginous minerals with which they are known to abound. It is obvious also that, in a majority of instances, this change took place in the original repositories of these minerals, since no perceptible derangement is discoverable in the layers of the ore-bed, or want of conformity in them to the adjacent rock. This view, adding limestone to the rocks, has been found by Dana to accord fully with the various facts in the limonite region of western Connecticut and Massachusetts." *Amer. Jour. Sci.*, (iii.) Vol. IX., No 54, p. 437, 1875.

Sibirtzev, N. [Preliminary account of Geological researches made in 1887.] *Bull. Com. Géol.* No. 3, pp. 95-107. 1888. St. Petersburg.

"Considers iron ore to be formed by change of Permian and Carboniferous limestone."

———. [South-eastern part of Sheet 72 of the Geological map of Russia.] *Bull. Com. Géol.* No. 2, pp. 43-52. 1889.

"Considers the iron ores to be the result of the replacement of carboniferous limestone."

Silliman, B. *Am. Jour. Sci.* (iii.) xxiv, p. 375. 1882.

———. On the Magnetites of Clifton. *Trans. Am. Inst. Min. Eng.* Vol. I, pp. 364-371.

Simmons, W. The Metallic Ores of Cornwall. Group 1. Tin, Copper, Iron and Lead. *Proc. Liverpool Geol. Soc.*, vol. iii. Pt. I. pp. 28-35. 1875.

Six, A. Sur l'origine et le mode de formation des minerais de Fer liasiques. *Ann. Soc. Géol. Nord.* t. x, p. 121. 1883.

Sjogren, A. [The connection between the manner in which ores appear and the relative ages of the rocks in which they are found.] *Geol. Fören. Stockholm Förh.*, Bd. iii, pp. 2-13.

"It is now generally accepted that the ores of Sweden form beds or ellipsoidal masses (lagerstockar), and cannot be classed as veins. The author arranges the Swedish iron-ores under the following heads:—Quartzose and felspathic ores, pyroxenic and hornblende ores, manganesian and calcareous ores.

The ores of the first group are characterized by their striated appearance, by the percentage of quartz and felspar, by the presence of phosphorus in a greater or less degree (possibly owing to the felspar), by a total absence of minerals belonging to the augite or hornblende types, and by limestone beds. Apatite is occasionally present. These ores, which are seldom found in large quantities, consist of magnetite and hematite.

The ores of the second group consist of magnetite, and are found together with malaccolite, coccolite, hornblende, asbestos, talc, chlorite, garnet, serpentine, epidote or other varieties connected with these minerals. They are often richer, purer and more ductile than the others, contain but little phosphorus, and are usually fused without the aid of fluxes, yielding a good and strong iron.

The ores of the third group are principally distinguished by their manganiferous and calcareous character and the large quantity of *sulphurous metals* which they often contain. Among the associated manganitic minerals, the following chiefly occur:—Hausmannite, rhodonite, manganese-spar and ruebelite. As a rule these are magnetic iron-ores.

In the author's opinion, these groups belong to different geological ages in the order above given, from the older to the newer—the first group occurring in connexion with pure gneisses, and the two others with euristic and felsitic rocks. (Hällefinta)." *E. Erdmann, Geol. Record*, 1874, pp. 96, 97.

———. [Occurrence of the Taberg Iron-ore deposit of Smaland, Sweden.] *Geol. Fören, Stockholm Förhandl.* Bd. iii, pp. 42-62. 1876.

The hill of ore is 420 Swedish feet high, 3,000 long, and 1,500 broad. It consists of an almost homogeneous eruptive rock, composed of olivine and magnetite, with grains of plagioclase, viridite and serpentine.

———. *Neues Jahrb. f. Mineral.* p. 434. 1876.

Smith, C. On Red Hematite. *Coal and Iron Trades Gazette*, p. 172, 1877.

———. The distribution of Spathic Iron Ore. *Journ. Iron and Steel Inst.* No. 12, pp. 152-165. 1874.

———. The Iron Ores of Sweden. *Jour. Iron and Steel Inst.* No. 2, pp. 310-319; *Coll. Guard.* vol. xxviii, p. 444. 1874.

Smith, Dr. Eugene A. Geological Survey of Alabama. Report of Progress for 1874. Pp. 139. 8vo. *Montgomery.* 1875.

———. Iron Ores of Alabama. *Proc. A.A.A.S.*, 1878, p. 246, *et. seq.*

"There seems to be very little doubt that the limestones and chert of the Quebec Dolomite, and the Siliceous group of the sub-carboniferous formations, have by their disintegration furnished the iron, for most of the ore occurs mingled with the sands, clays, broken masses of chert and other débris which have evidently come from the disintegration of cherty limestones. Nearly every hillock, upon the two formations mentioned, shows more or less of iron-ore as surface specimens, and many of the sandy clays have the deep red color due to the peroxide of iron. Where the iron has accumulated we have the ore banks." * * *

"Whilst most of the limonites found in our ore banks may have been formed long since, yet wherever a ferruginous solution from precipitation, evaporation or other cause, deposits its iron, we have the conditions of forming an ore of iron, limestone, chert or other ore. It may be that even now, every rain that falls upon the ferruginous, sandy clays, in which most of our limonites are imbedded, may help in the formation of limonite which at some future day may be utilized in the blast furnace." * * *

"Prof. Safford, (Geol. Tennessee), is of the opinion that the source of the iron may be looked for in the ferruginous chert, whilst the formation of the ore masses, as we now find them, has probably taken place at a comparatively recent date, perhaps subsequent to the time when the pebbles and sands, associated with much of the ore, were deposited."

Smith, J. L. [Native Iron of Greenland and the Basalt which contains it.] *Compt. Rend. t. lxxxvii*, pp. 674-676; and, under slightly different title, *Bull. Soc. Min. France*, No. 5, pp. 90-92. 1878.

"Thinks that the iron is of terrestrial origin, and probably a secondary product formed by the reducing action of the lignites and other organic matter which the basaltic dykes have penetrated."

Smith, Josiah T. Iron Ore Requirements of Great Britain. *Jour. U. S. Assoc. Charcoal Iron Workers*, vol. 8, No. 4, pp. 251-258. 1889.

Smock, Prof. J. C. The use of the Magnetic Needle in searching for Magnetic Iron Ore. *Trans. Amer. Inst. Min. Eng.* Vol. iv, pp. 353-356. Iron, n. s. vol. viii, p. 585. 1876.

———. The Magnetic Iron Ores of New Jersey. Their Geographical Distribution and Geological Occurrence.

Trans. Amer. Inst. Min. Eng., vol. ii, pp. 314-326. 1875.

"The granitic rocks that contain magnetite generally cut the beds of gneiss, and are huge ore-bearing dykes. Being contemporaneous with the gneissoid rocks, the ore-beds have been subject to the disturbing forces that have effected them."

———. First Report on the Iron Mines and Iron-Ore Districts in the State of New York. *Bull. N. Y. State Museum*. 1889. 70 pp. with map

Smyth, F. Warrington. *Quart. Jour. Geol. Soc.* Vol. 15, pp. 105-109.

Regards iron ore deposits as occurring principally in veins, but partly also in beds. He says: "Ores of iron occur both in regular strata and in veins; * * * the occurrence of a small vein on the east side of the hill, coursing N. N. E., is additional evidence in favor of the true vein-character of these deposits. * * * a series of parallel fissures have been opened in planes very nearly concordant with those of the general stratification, and have then been filled with carbonate of iron, some quartz, and fragments of the containing rock. Some of these, with the slates, have afterwards been subjected to various disturbances, the results of which are seen in heaves and slides, as at Goosemoor near Bearland Wood, &c."

Smyth, W. W. Report on The Iron Ores of Great Britain. *Mem. Geol. Sur. Gt. Britain*, p. 19. 1856.

"There is little doubt that the brown ore is due to the decomposition effected by atmospheric or *anogenic* action, and that it was all originally placed *in situ* in the condition of a carbonate."

———. Iron Ores of the Shropshire Coal Field, and of North Staffordshire. *Mem. Geol. Sur.* Iron Ores of Great Britain. Part iv, 8vo., pp. 60. 1862.

———. The Ores of Iron considered in their Geological relations. *Coll. Guard.*, vol. xxix, pp. 737, 738, and *Min. Journ.*, vol. xlv, p. 550. 1875. Also *Journ. Iron and Steel Inst.*, pp. 43-54. *Iron*, vol. v, p. 714.

Sokolov, N. [Description of the region embraced in Sheet 48, Geological map of Russia.] *Mem. Com. Geol.*, vol. ix, No. 1. pp. i-viii; 1-245. 1889.

Sorby, ———. On Cleveland Hill Ironstone. *Proc. Geol. and Poly. Soc. of the West Riding*, p. 458. July, 1856.

———. Nature, xv, 498. 1887. Native Iron in the Basalt of Greenland.

Spencer, J. W. Economic Survey in Georgia and Alabama, throughout the belt traversed by the Macon and Birmingham railway, 86 pp., map. *Athens, Ga.* 1890.

Stahl, Georg Ernest. Specimen Becherianum. *Leipzig.* 1703. Published with Stahl's edition of Becher's *Physica Subterranea*.

———. *Treatise de Ortu Venarum Metalliferarum.* 4to. *Magdeburg.* 1700.

Stabler, H. *Berg- u. Hüttenm. Zeitung.* 1867, p. 17.

Stapff, F. M. *Berg- u. Hüttenm. Zeitung.* 1868, p. 403.

———. *Berg- u. Hüttenm. Zeitung.* 1865, pp. 6, 18 and 29.

Stanard, B. A. Stanard's Rock. In the "Mineral Regions of Lake Superior," by J. Houghton, Jr., and T. W. Bristol, p. 81.

Stead, J. E. Phosphorus in Iron Ore and in Iron. *Proc. Cleveland Inst. Eng.* Sess. 1876-77.

Steavenson, A. L. Ironstone Mining in Cleveland. *Journ. Iron Steel Inst.* No. 2, 1874, pp. 329-337.

Steenstrup, K. J. T. [The Nordenskiöldian iron masses and the occurrence of native iron in basalt.] *Vid. Medd. Nat. Fören. Kjöbenhavn.* No. 16-19, pp. 284-306. 1875.

"Thinks that the large blocks of native iron which Nordenskiöld discovered at Disko, North Greenland, are not meteorites, but that the iron belongs to the neighboring basalt."

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Swank, Jas. M. History of the Manufacture of Iron in all Ages. *Philadelphia*, 1884, pp. 428.

———. A Bird's-Eye View of the Iron Ores of the United States. *Philadelphia*, 1885. *Am. Iron and Steel Assoc.*, pp. 31. Contained in *Mineral Resources of the U. S.*, by **A. Williams, Jr.** 1885.

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Tate, A. N. Notes on Ferruginous Bands in the Sandstones of this District. *Trans. Liverpool Geol. Soc.*, vol. ii, pp. 63, 64. 1882.

Tate, Ralph, and John Sinclair Holden. On the Iron Ores associated with basalts of the northeast of Ireland. *Q. J. G. S.*, Dec. 1869, vol. xxvi. Pt. I., p. 151.

"Suggested Theories.—Four theories may be suggested to account for the origin of the (pisolitic) iron ore; these are:

(1) *Sedimentary theory*, which implies a derivative origin, but is at variance with the petrological features—the distribution of the mineral particles has evidently been regulated by some other force than that of gravity. Mr. Du Noyer, in a paper on the geology of Island Magee, read before the Natural History and Philosophical Society, of Belfast, November 25, 1868, endeavored to demonstrate that the iron ore in the basalt of Island Magee was entirely due to the action of water, 'that it was as true an aqueous conglomerate as if it had been formed in the heart of the Old Red Sandstone.' From this opinion we most emphatically dissent, though at the same time we fully concur with him when he assigns such an origin to the iron beds at Ballypallid.

(2) *Theory of deposition*, implying either a precipitation of the ferruginous material from chemical solution, or segregation by organic agency. We believe that the state of combination of the oxides of iron, the intimate structure of the spheroids, and the petrology necessitate some other explanation.

(3) *Igneous theory*, implying production by direct volcanic action. Though specular iron is enumerated among the minerals emitted from active volcanoes, and magnetite and iron pyrites are accessory constituents of several of the basaltic strata, yet such an origin does not meet the requirements of the case in point. The distribution of the spheroids of pisolitic ore demands either a shower of the ferrous nodules over a large area, the smaller ones falling before the larger, or a flow of volcanic mud with suspended spheroids, the smaller sinking first in the mass—both assumptions being highly improbable.

(4) *Metamorphic theory*. It is only by metamorphism that all the phenomena connected with the pisolitic ore can be interpreted. By metamorphism we understand nothing more than the effects of heat, and employ the term in its widest significance."

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———. On the Economy of the Mines in Cornwall and Devon. *Geol. Trans.*, vol. ii, ser. 1, p. 309. 1814.

———. Report on the State of Knowledge Respecting Mineral Veins. *Trans. Brit. Assoc. Adv. Sci.* 1833. pp. 1-25.

Gives considerable attention to Werner and quotes his resumé of early theories of the formation of veins. Says that all who have preceded him have erred in attempting to account for all metalliferous deposits upon some one hypothesis. He states that that there are three theories which may account for the formation of all veins.

1st. That which supposes them to have been open fissures, caused by disruption and occasioned principally by subsidence of parts of the rocks, which fissures were afterwards filled up with various matters by deposits from aqueous solution, chiefly from above. Modifications of this theory are: That such rents in the earth may have been caused in other ways, such as earthquakes or certain great convulsions, as well as by subsidence: that they may have been filled by infiltration of solutions, which deposited the substances with which they were charged in the veins, or by the process of sublimation from below.

2nd. That veins were formed subsequently to the consolidation of the rocks; but the cause principally assigned for such fissures is the violence done to the strata by the elevation or upheaving of other rocks from below. And it is an essential part of this theory that the materials which fill the veins were forcibly injected upwards in a state of complete fusion by heat.

3rd. Denying any subsequent processes which might either cause rents and fissures, or might fill them with matter which differs from the rocks which enclose them, the whole formation was contemporaneous with the rocks themselves, the mineral substances which we find in veins having separated and arranged themselves into the forms in which we now find them to exist. * * *

"That certain veins have been filled by injection from below and with matter in igneous fusion, seems to be rendered certain by evidence which is clearer than most we possess on such subjects, and must be admitted at once. Thus when we see a trap dyke traversing a bed of coal and charring the combustible matter, and affecting the rock itself with visible effects of great heat, we must assent to the cause assigned. . .

"The theory of the filling up of veins by precipitation from aqueous solutions is defective in not being able to show what menstruum could render such substances soluble in water; and this difficulty must remain an important one unless enlarged knowledge should hereafter afford the means of explaining it.

"As we cannot easily conceive how the metallic ores can have been deposited from solution in water, and appearances are much against their having been injected in a state of fusion, there is another supposition which, though not free from difficulties, has yet probability enough in its favor to have gained many supporters—which is that these and some other substances have been raised from below by sublimation."

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———. Revue des Progrès récentes de l'Exploitation des Mines, etc., par **M. Haton** de la Goupillière, Ingen. en chef des Mines, etc. *Ann. d. Mines*, t. xvi., p. 6. 1879.

Thiessing, Dr. J. [Mineral Processes of Switzerland.] *Emul. Jurass.* 1 ann., pp. 53-64. 1876.

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Tholander, H. Experimental Researches on the Reduction of Iron Ore and on the effect of Roasting upon Magnetites and Hæmatites. *Iron.* n.s.; vol. viii, pp. 418, 482. 1876.

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Thomson, Dr. Mineralogical Observations on Cornwall. *Annals of Philosophy*, vol ii, pp. 247, 346. 1813.

Thoreld, A. F. [Have we any true Knowledge as to the Length of Time Necessary for the Generation of the Lake- and Bog ores? and if so, how long is this time?] *Geol. Fören. Stockholm Förh.* Bd. iii, pp. 20-40. 1876.

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"The ore occurs in an extensive vein running northwest and southeast. At the surface it is somewhat spongy, but becomes compact and dense as the depth increases. Although a magnetite, it contains excess of ferric oxide. The analysis shows it to contain from 40.10 to 72.46 of magnetic oxide; the sp. gr. is 4.31. A quantity sent to Staffordshire has been smelted with good results. Considers that this vein is of aqueous origin, but attributes the formation of the magnetic oxide to thermal influences under pressure on partially oxidized solutions. Describes laboratory experiments bearing out this point."

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Torell, Prof. Otto. [Report on the Iron and Copper Ore Districts of Lapland, in Sweden.] pp. 144, 4to. *Stockholm*. 1877.

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"Contains some account of the mountains of magnetite at Wyssokaya and Blagodat."

Tschernyshev, Th. [A Geological Excursion to the Urals in 1888.] *Bull. Com. Géol.* No. 5, pp. 121-141. 1889.

"He has made a detailed study of the structure of the Blagodat mountain, celebrated for its mines of magnetite; the relations between this mineral and the surrounding rocks (porphyritic granite and syenite) are exactly defined, as well as the conditions under which magnetite is produced and deposited."

———. [Description of the central part of the Urals and the western slope.] *Mém. Com. Géol.* Vol. iii. No 4; pp. i-viii; 1-320. 1889.

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Tunner, P. Ritter von. [Metallurgy of Iron in the United States.] 3 pls. 8vo. *Vienna*. 1877.

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- Urbanek, —.** Spatheisensteinvorkommen in Syenit bei Brunn. [Iron-ore in Syenite of Brunn.] *Verh. nat. Ver. Brunn*, Bd. xiii, p. 35. 1875.
- Vala, Jos., and R. Helmbacker.** [Iron-ore between Prague and Beraun.] *Arb. geol. Abth. Land. Böh.* 1 Theil 11, Bd. ii. Abtheil. pp. 99-407, 1874.
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- Van Doren, J. L.** Prospectus of the Missouri Iron Company. Boston, 1837, pp. 40. Contains extracts from letters and reports by Schoolcraft, Featherstonhaugh, Dr. Newton May, John F. Cowan, Alphonso Wetmore, James Baily and others.
- Van Hise, C. R.** *Am. Jour. Sci.* (iii) vol. xxxvii. Jan. 1889. Holds same opinion in general as Irving, i. e. "that the iron formation deposits were originally an impure cherty carbonate of iron." p. 45.
- Vanuxem, Lardner.** Geology of the Third District, New York. 2d. An. Report. 1838, p. 268.
 "In this series of rocks commence those beds of red oxide of iron which have long been worked in Oneida county. The number of beds varies from local causes. In Herkimer they are from one to two, in Oneida from one to three, depending, as I fully satisfied myself, upon the nature of the surface over which the iron flowed. If the surface was permeable the iron was absorbed by the mass, coloring the rock. If on the contrary, impermeable, a bed of ore was the result. On page 284 we find: *Prolean Group*.—This mass is about two hundred feet in thickness, consists of green and blue shales, green, red and white sandstones, red oxide of iron, gypsum, etc. The red sandstone of Herkimer shows that the iron has passed through the rock by infiltration; much of it presenting its grains of sand enveloped by minute crystals of oligiste or specular iron, the appearance which belongs to the red oxide when in a crystalline state."
- Vennor, Henry G.** Geological Survey of Canada. Rep. Prog. 1872-3. p. 175; 1874-75, pp. 112-122; 1876-77. p. 296.
- Verbeek, R. D. M.** West Coast of Sumatra, Verslag No. 11. [Iron-ores near Goenoeng-Bessi.] *Jaarb. Mijn. Ned. O.-Ind.* dell. 1, p. 39, 1877.
- Vicuna, G.** [Iron in Biscay.] *Rev. Min.* sér. B, t. 1, pp. 130, 137, 142, 1875.
- Vieira, —.** [Iron-ore deposit of Rancié.] *Rev. Géol.* t. xii, pp. 92-94.
- Vinton, F. L.** Leadville and the Iron Mines. *Eng. Min. Journ.* vol. xxvii, p. 110, 1879.
- Virlet d' Aoust, T.** Rapport sur les mines de fer oxydé manganésifère d'Escoumps (Pyrénées orientales), 4to. Pp. 12, 1882.
- Vivian, W. M.** Notes on a deposit of Iron-ore at Marbella, Province of Malaga, Spain. *Proc. S. Wales Inst. Eng.*, vol. xiv, pp. 48-52, 86, 1884.
- Vogdes, A. W.** Notes on the Distribution of Iron Ores in the United States. Ft. Monroe, Va. 1886.
- Voigt, —.** *Bergbaukunst*, 1789, 2 vols; *Magazine d. Naturkunde*, 1806, p. 478; *Moll's Annalen*, 1808, vol. vii, p. 174.
 Describes the Iron Ore deposits in the Thuringian Forest.
- Von Cotta, Bernhard.** *The Geologist*, p. 36, 1863.
- . Erzlagerstätten in Banat und Serbien. *Vienna*, 1864, p. 100.
 Considered the iron ores of Banat igneous.
- . A Treatise on Ore Deposits. Translated by Frederick Prime, Jr. New York. 1869.
 In this work the origin of iron ores is treated of in many places. On page 507 he says:
1. "Spathic iron forms *lodes* (or veins) *beds* and *bedded segregations*, in clay-slate, Zechstein, etc.

2. *Sphaerosiderite* and *clay-ironstone* form *beds*, or lenticular masses, parallel to the foliation, in almost all deposits, and bituminous shales; also as grains, in an Eocene sandstone, on the northern edge of the Alps.

3. *Magnetite*, very frequently with somewhat of specular iron, chlorite amphibole, garnet, quartz and numerous other minerals, forms *beds*, *lodes*, or *veins*, *segregated masses* and *impregnations* in crystalline schists, near their junctions with granular limestone, or of basic igneous rocks.

4. *Chromic iron*, almost everywhere associated with serpentine or gabbro; a small admixture of chromic iron is probably never wanting in these rocks, but the same sometimes forms *masses*, *segregations*, or the *filling of fissures* in the same which can be mined.

5. *Specular iron*, forms *lodes* in crystalline schists, and igneous rocks, even in lavas; at times associated with quartz, *lievrite*, etc. As *beds* of micaceous iron schist, between chloritic schist, itacolumite, or granular limestone, combined with quartz.

6. Hematite, compact, ochreous or fibrous, more rarely oolitic; frequently with ores of manganese, quartz, limestone or clay; more rarely with carbonates, heavy and fluor-spar; forms *beds*, *lodes* and *contact-segregations*, for the most part in crystalline schists, or at least in old sedimentary formations; often at the limits of crystalline limestone, or also at the limits of plutonic igneous rocks, at the same time forming *lodes* in these; the hematite in the Erzgebirge appears to be principally associated with granite or quartz-porphry.

7. *Limonite*, compact, ochreous or fibrous; with the same accessory minerals as hematite, also under the same conditions of bedding, but extending into the most recent sedimentary strata: the accompanying limestone is as frequently compact as granular, the igneous rocks, at whose limits *contact-deposits* occur, are also volcanic, as for example, basalt."

It thus appears that he recognizes various methods of origin for iron ores. As to the origin of ore-beds he remarks, p. 22:

"There can be no doubt that all true ore-beds were originally formed by mechanical or chemical precipitation from water. Their condition may have been much changed afterwards; thus under certain conditions hematite may have been formed from limonite, etc.; but their origin remains a precipitation. However certain this may be, still the origin of metalliferous portions of some of the beds remains unexplained.

"Iron is a metal so widely distributed in its various forms, so common to all rocks, and held in solution in so many springs, that the origin of the strata in which it predominates, appears by no means obscure. On this account deposits of iron-stone only require an explanation of their state of aggregation and manner of occurrence in each particular case."

It thus appears that Von Cotta had in mind the germ of the theory which is advocated in this report, viz., the chemical precipitation of certain iron-ores contemporaneously with the formation of the beds of rock in which they are found. But in no place do we find him referring to any specific ore-deposit as having been precipitated in oceanic waters. On p. 546 he again advances the same idea:

"True beds have evidently been formed in a manner analogous to that of the strata enclosing them, through mechanical or chemical precipitation from water. * * * * Limonites are deposited before our very eyes on the earth's surface from ferruginous waters, from which beds of hematite and magnetite could be formed under the influence of heat and pressure; as well as from these latter beds, near the surface, limonite might again be formed.

"The deposit of carbonate of iron is far more difficult to explain. For example, the sphaerosiderites of various formations, or strata containing coal; since in the presence of the atmosphere, carbonate of iron is never precipitated from a carbonic-acid solution; but, owing to the rapid decomposition of the same, always hydrated peroxide of iron. Only when covered (preventing the influence of the atmosphere) can sphaerosiderite, or spathic iron, be deposited. Therefore their formation in the depths of a vein-fissure is easily explained, but it will not apply to a bed at the surface; these were perhaps formed under a considerable depth of water.

"It appears to me, therefore, questionable whether these last named ores, where they occur as beds, were everywhere originally formed as such, or whether occasionally oxidized deposits have not first subsequently absorbed carbonic acid, . . . just as compact limestone has been converted to marble, so could crystalline spathic iron have been formed in an analogous manner from beds or masses of compact sphaerosiderite, through a subsequent crystallization of the mass, of course under the long continued effects of pressure, heat and moisture. Perhaps on this account beds of spathic iron are always found only in older deposits, never very recent ones.

"It is an ascertained fact that limonite is formed from spathic iron, or sphaerosiderite, through the effects of atmospheric causes. Under other circumstances, beneath a considerable covering, hematite and magnetite appear to have been formed from the limonite."

Von Cotta believed that veins of iron ore can be and have been produced by other agencies than aqueous solution and deposition. On page 78 we find:

"It is further beyond a doubt that at times clefts in volcanoes are filled with sublimed ores, especially specular iron, which was reduced from vapors of proto-chloride of iron. Lodes of specular or micaceous iron, and similarly many other lodes, may have been formed in the same manner at earlier periods in the history of the earth. We must also here know the special case before we are able to form an opinion.

"It is, also, by no means impossible that certain ores, coming in an igneous-fluid condition, not from the central hearth of the igneous rocks, but from the re-melting of the already existing metallic deposits, should have penetrated fissures and solidified in them, although no cases of this kind are known, as being formed at the present

time, or near the earth's surface. We are as yet too little acquainted in this relation with the results of high pressure."

He refers, on page 74, to the fact that Plattner proved the formation of magnetite by sublimation in the Freiberg reverberatory furnaces, and refers to his work, "*Gangstudien*," vol. II, p. 1.

On p. 91 he says: "That beds or impregnations of magnetic iron or specular iron were not originally deposited by water as such, is self-evident; but they are always and only found in metamorphic rocks, as chlorite-schist, mica-schist, etc., and were subsequently subjected to the same catogene influences as the matter from which the rocks sprang. The peroxide of iron, and under certain circumstances the protoxide, might be formed from the hydrated peroxide of iron. Similar events might have taken place in other metallic beds, and the accompanying or independently occurring ore-impregnations, which are found in crystalline schists. This circumstance may explain many otherwise unintelligible phenomena."

On the origin of Spathic iron we find still further considerations on p. 346. "The origin of these deposits (Erzberg) is still very enigmatical. In so far as they are true beds, the mineral matter composing them must have been deposited, during the Devonian period, between the beds enclosing them. But in what condition? Hardly as crystalline spathic iron. It might be supposed that they were formerly sphärosiderite, and had become crystalline through a long continuing period of pressure and warmth. Such a hypothesis would also allow the consideration that the neighboring veins of spathic iron had been pressed in a softened condition from the veins into the fissures. But where do such thick beds of sphärosiderite occur? and, in any case, the manner in which the sphärosiderite was formed still remains an unsolved problem."

On pp. 502, 503, is still further discussion on spathic iron, where ideas similar to those quoted are advanced.

On p. 225 we find the following: "A perpendicular vein of magnetite, 30 feet broad, crops almost out to the surface, at the junction of the Silurian and Azoic slates, north-erly of the village of Glashütten, in the lordship Raditz."

The magnetic iron ore is enclosed towards the surface, by limonite and hematite, with layers of slate; and is generally so intimately combined with the clay-slate that it might be called a clay-magnetite. It is a very remarkable fact that this ore, near the surface, attracts and is polar; at a depth of 14 feet it only repels, and at a depth of 30 feet is no longer magnetic. From this it would appear as if the magnetic force had first been excited by the influence of the atmosphere."

On p. 132 he describes some deposits of iron ore very similar to some in the Lake Superior region.

"In the graywacke rocks between Christgrün and Stenn, near Zwickau, occurs a succession of greenstones which are accompanied by iron ore deposits of a peculiar kind.

"As these deposits principally occur at the limits of the greenstones, they may be comprised under the general name of contact-deposits: though at times they are found altogether within the greenstones, or at some distance from them in the slates. Though clearly of a vein-like character, these deposits are distinguished from the iron lodes of the upper Erzgebirge and western Voigtland (occurring as true fissure lodes), not only by the irregularity of their extent, as well as of their strike and dip; but also by the frequent absence of salbands. The frequent transition of their matrix from limonite and hematite, either pure or somewhat deteriorated by intermixture with chlorite, quartz and calc spar, through more or less ferruginous greenstone or slate, into the totally barren country rock, shows a greater resemblance to certain classes of beds. They appear at times extending for a considerable distance in length and breadth forming vein-like masses several fathoms broad, at times following the greenstone limits and slates in the most fantastic curves; at times occurring as broad, bed-like zones, of extremely ferruginous Azoic or Silurian slate, between non-metalliferous layers of this rock; again as pockets or nests in the midst of decomposed greenstone, which not seldom are of considerable breadth and extent. Near the surface their ore is chiefly massive or earthy limonite with somewhat of goethite, or at greater depths these are replaced by hematite in various degrees of purity."

The formation of bog iron ore is spoken of on pp. 255-256, as follows:

"The formation of bog iron ore, where it is still going on, is very instructive. It is formed by deposits from water which frequently contain very small quantities of iron dissolved in it. The long continuation of the process of deposit, here, completely replaces a greater energy of action, and it is probably the same in the formation of many other ore deposits."

"The iron content of the water evidently originates in the rocks from which the springs rise, even the most sparing and finely disseminated iron contents of the rocks are gradually dissolved and carried away by the water. When this water reaches low and marshy land, stagnating under circumstances where it is exposed to a strong evaporation, or where living or decomposing organic bodies exercise a peculiar reaction upon it, the deposit of oxide of iron takes place, and with this the concentration, in a special deposit, of a formerly, perhaps widely disseminated content of iron. A similar event may take place somewhat more rapidly where springs arise from very ferruginous deposits, or even from certain iron ore deposits; but as a rule, the formation of bog iron ore has no such special cause."

According to Ehrenberg, small living Infusoria also occasionally take part in the formation of the hydrated peroxide of iron, since they construct their shells of it, as do many species of *Gaillonella*. After their death their shells remain, as collections of a fine ochreous iron, which perhaps subsequently hardens and becomes a firm mass."

The theory of the formation of mineral-veins or lodes by electricity is referred to by Von Cotta on pp. 58, 59.

"It has frequently occurred that an essential influence on the contents of lodes and particularly on the unequal distribution of ores in them, has been ascribed to the elec-

tric currents which may possibly arise from the superposition or contact in any way of somewhat similarly composed rocks. This hypothesis was founded on the fact that during the decomposition of a solution by a voltaic current dissimilar substances are deposited at the positive and negative electrodes. Fox, in fact, by means of artificially obtained electric currents, not only produced fissures in clay, but also filled these fissures with metallic substances. In consequence of this he is of the opinion that electricity has exerted a great influence in the arrangement of minerals in lodes; he believes in particular that the greater richness of many lodes, on passing from one rock to another, can be explained by supposing that the electro-negative acting rock must have caused a greater deposit.

The fact of electric currents existing in the earth's crust is, however, somewhat uncertain. Prof. Reich, indeed, obtained deviations of the needle when he connected two different points of a lode by means of conducting wires; but he explains this very clearly through the contact of the various ores composing the isolated groups of ore, which are separated by sterile rock acting as a moist conductor. According to this the electric currents were first caused by the distribution of the ores in the lodes; and the reverse cannot as yet be deduced, namely, that this distribution has been caused by such currents. By connecting points free of ore, Reich was unable to obtain the slightest deviation."

Von Cotta, B. *Berg.- u. Hüttenm. Zeitung.* 1861, pp. 58, 155; 1864, p. 118; 1869, p. 29.

Von Miller. *Berg.- u. Hüttenm. Jahrb. d. k. k. Bergakademien*, 1864. No. 12.

Considers ironstones of Eastern Alps as belonging to the Triassic.

Von Morlot. *Jahrb. d. geolog. Reichsanst.* 1850, pp. 104, 118. Iron Ores in the Eastern Alps.

Von Oppel. *Anleitung zur Markscheidekunst.* 1749. *Bericht von Bergbau.* 1749.

Von Rath. *Leonhard's Jahrb.* 1865, p. 98. On Iron Ores of Elba.

Von Schuppe. *Jahrb. d. geolog. Reichsanst.* 1854, p. 369. Iron Ores in the Eastern Alps. Considers them bedded.

Wadsworth, M. E. *Proc. Bost. Soc. Nat. Hist.*, xv, pp. 470-479. 1880.

"I hold that they (iron ores of Lake Superior) are chiefly eruptive, partly intrusive, partly in overflows; also formed in part by decomposition of the jaspilite and ore *in situ*, and in part by mechanical and chemical deposition, Op. C., Vol. XVI., p. 103.

———. *Bull. Mus. Comp. Zool. Geol. Ser.*, 1, p. 75. 1880.

"The general structure of the country would seem to be as follows: The schists, sandstones, etc., having been laid down in the usual way, were then distributed by the eruption of the jasper and ore; this formed the knobs of jasper, the banding belonging to fluidal structure and not to sedimentation. Besides occurring in bosses, the jasper was spread out in sheets, and intruded through the rocks in wedge-shaped masses, sheets and dikes." "The iron-ores are regarded as all of sedimentary origin by Foster, Kimball, Dana, Hunt, Winchell, Credner, Brooks, Newberry and Wright, but are believed for the most part to be of eruptive origin by Whitney, and Foster and Whitney." P. 27.

———. Notes on the Rocks and Ore Deposits in the vicinity of Notre Dame Bay, New Foundland. *A. J. Sci.* iii, vol. xxviii, pp. 94-104. 1884.

———. On the Origin of the Iron Ores of Marquette District of Lake Superior. *Proc. Bost. Soc. Nat. Hist.*, vol. xx, pp. 470-481, 1881; and *Eng. Min Jour*, vol. xxxii, no. 18, p. 286, 1881. See also *Amer. Jour.* ser. 3, vol. xxii, pp. 403-407, 1881.

———. Lithological Studies. *Memoirs Mus. Comp., Zool.*, vol. xi, pt. 1. 1884. 4to., pp. 208, xxxiii, plate 8.

"In its oxidized forms, and in association with a rock belonging at the other extreme of the lithological scale, siderolite occurs on the southern shore of Lake Superior." p. 64.

"It is probable that but few will claim that the siderolites of meteoric origin were formed by organic agencies. If they were not, it follows that the graphite contained in them could not have been so produced. This has a very direct and obvious bearing on the question whether the graphite in Azoic and other rocks need have been derived from animal or plant remains, and it negatives the supposition*."

"To make graphite the evidence of life is the same kind of argument as it is to claim that no oxides of iron and no carbonate of lime could be found without the intervention of life. One we knew to be oftentimes of volcanic origin, and the other to be frequently the product of the decomposition of rocks." (*Loc. Cit.*, p. 67.)

* J. Lawrence Smith, *Mineralogy and Chemistry*. 1873, pp. 284-310; *Am. Jour. Sci.* 1876 (3) xi, 388-395, 433-442; Walter Flight, *Pop. Sci. Rev.* 1877, xvi, 390-401.

———. The Theories of Ore Deposits. *Proc. Bost. Soc. Nat. Hist.* 1884.

Waldenstein, Joseph W. von. Die besonderen Lagerstätten der nutzbaren Mineralien. *Vienna.* 1824.

Walter, Bruno. [Ore Deposits of S. Bukowina.] *Jahrb. k. k. geol. Reichs.* Bd. xxvi, Heft. 4, pp. 343-426, 1876.

Ores lie generally parallel to the strike of the beds of the formations. True veins are mostly absent, most of the occurrences being analogous to that of a Swedish "fahlband."

———. *Jahrb. d. k. k. geol. Reichsanst.* 1876, p. 391 and 415. — v. Cotta, *Erzlager-Stätten*, II, p. 260.

Ward, J. C. The Geology of the Northern Part of the English Lake District. *Geological Survey Memoir.* 8vo. London. 1876.

Wedding, Dr. H. *Zeitsch. d. deutsch. geol. Gesell.* 1859. p. 399. On Iron Ore deposits near Schmiedeberg.

———. *Zeitschr. d. d. geol. Gesellsch.* vol. xi. 1859, p. 399; *Zeitschr. f. d. Berg- u. Hutten. u. Salinenw. im preuss. Staat*, vol. xxiv, 1876, pp. 330, 336, 345, 346. Contains descriptions of the Michigan and other Iron Ore districts.

Weed, Walter H. The formation of Travertine and Siliceous Sinter by the vegetation of hot springs. *Ninth Annual Report U. S. Geol. Sur.* 1887-88. pp. 619-676; *Am. Jour. Sci.* iii. xxxvii, May, 1889, pp. 351-359.

Weibye, —. *Leonhard's Jahrb.* 1847, p. 697. Iron Ores of Arendal, Norway.

Weidner, Henrico. Cerro de Mercado. Report to the Mexican Minister of the Interior. 1858. 2nd Ed. 1878.

Does not think that it is meteoric, nor that Baron Humboldt referred to samples from this mountain when he speaks of enormous masses of malleable iron and nickel found in the neighborhood, (Political Essays on the Kingdom of New Spain, bk. 3, chap. 3, paragraph 2, Spanish ed., 1827). Weidner says: "I have not had a moments doubt in considering the *Cerro de Mercado* an eruptive volcano, denying thus the meteoric origin that has been so freely attributed to it." (*Trans. Am. Inst. Min. Eng.* for 1884. Paper on Cerro de Mercado by John Birkinbine).

Wendt, A. F. Tilly Foster Iron Mine. *Trans. Am. Inst. Min. Eng.* xiii, pp. 478-484.

Werner, Abraham Gottlob. New Theory of the Formation of Veins with its application to the art of working mines. German Edition, 1791. Translated by Charles Anderson, M. D., 1809. *Edinburgh.* 8vo, 23 pp., with an appendix by the translator.

Wethered, E. On the Origin of the Hæmatite Deposits in the Carboniferous Limestone. *Coll. Guard*, vol. xlv, p. 334, and *Rep. Brit. Assoc.* for 1882, p. 533. 1882.

Whitehurst, John. Inquiry into the Original State and Formation of the Earth, p. 283. 1778.

Whitney, J. D. The Lake Superior Copper and Iron District. *Proc. Bost. Soc. Nat. Hist.*, 1849, iii, 210-212. Stated that Iron Ores are of igneous origin.

———. Iron Ores of the Azoic. *Proc. Am. Assoc. Adv. Sci.* 1855, pp. 209-216. *Am. Jour. Sci.* ii, vol. xxii, pp. 38-44. 1856.

Maintained that the iron ores of the Azoic system have had a similar method of origin. On p. 210 *op. cit.* we find him saying with regard to himself and Mr. Foster:

"We maintain, therefore:

1. That deposits of the ores of iron exist in various parts of the world, which in extent and magnitude are so extraordinary as to form a class by themselves. The iron regions above mentioned, (Lake Superior, Scandinavia, Missouri and northern New York), offer the most striking examples of the deposits now referred to.

2. That the ores thus occurring have the same general character, both mineralogically and in their mode of occurrence, or their relations of position to the adjacent rocks.

3. That these deposits all belong to one geological position, and are characteristic of it."

That he did not consider all iron ores as of eruptive origin is shown by following:

"Most of the veins which are wrought in mines throughout the world are but a few feet in width, often not more than a few inches. This is true of the ores occurring in veins. In sedimentary metalliferous deposits, such as those of the ores of iron in the Carboniferous, the horizontal extent is often very considerable; but the vertical range is so limited that the most extensive basins may be in time exhausted, when worked on so extensive a scale as is the case in some of the celebrated iron districts of Great Britain. * * * The mode of occurrence of these ores in the regions above mentioned is so peculiar, that from this point of view alone, it is apparent that these deposits should be classed together as distinct from those in the later geological formation. In all the characteristics of true veins, the great masses of ore now under consideration are wholly wanting. Some of the least important of them approach much nearer to segregated veins, and might with propriety be classed with them, were they not developed on so large a scale as to render it difficult to conceive of segregation as a sufficient cause for their production.

In the case of the most prominent masses of ore of these regions, there is but one hypothesis which will explain their vast extent and peculiar character. They are simply parts of the rocky crust of the earth, and like other igneous rocks, have been poured forth from the interior in a molten or plastic state. No other origin can be assigned to the dome-shaped and conical masses of Lake Superior and Missouri, or to the elongated ridges of the first-named region. * * * The eruptive origin of the great Lake Superior ore-masses seems also well sustained by the phenomena which they exhibit. They alternate with trapezian ridges whose eruptive origin cannot be doubted, and which, themselves, contain so much magnetic oxide disseminated through their mass, as one of their essential ingredients, that they might almost be called ores. These eruptive masses include the largest and purest deposits of ore which are known in the Lake Superior or the Missouri iron regions; but there are other localities in both these districts where the mode of occurrence of the ore is somewhat different, and where the evidences of a direct aqueous origin are less marked. This class comprehends those lenticular masses of ore which are usually included within gneissoidal rocks, and whose dip and strike coincide with that of the gneiss itself, but whose dimensions are limited. Such is the character of most of the Swedish deposits, and of many of those of northern New York. Such beds of ore as these may in some cases be the result of segregating action, but the facts seem rather to indicate that they are made up of the ruins of pre-existing igneous masses which have been broken and worn down during the turbulent action which we may suppose to have been preëminently manifested during the azoic epoch, and then swept away by currents, and deposited in the depressions of the sedimentary strata then in process of formation."

"There is still another form of deposit which is not infrequently met with in the Lake Superior region, and which may be seen in a grand scale on the Pilot Knob of Missouri. This consists of a series of quartzose beds of great thickness, and passing gradually into specular iron, which frequently forms bands of nearly pure ore, alternating with bands of quartz more or less mixed with the same substance. Some of the deposits in the Lake Superior region are of this class, and they are very extensive, and capable of furnishing a vast amount of ore, although most of it is so mixed with silicious matter as to require separating by washing before use. Heavy beds of nearly pure ore occur at Pilot Knob, interstratified with beds of poorer quality. Deposits of this character are usually very distinctly bedded, and the ore shows a greater tendency to cleave into thin laminae parallel with the bedding, in proportion to its freedom from silicious matter. These deposits seem to have been of sedimentary origin, having been originally strata of silicious sand, which has since been metamorphosed. The iron ore may have been introduced either by sublimation of metalliferous vapors from below during the deposition of the silicious particles, or by a precipitation from a ferriferous solution, in which the stratified rocks were in process of formation."

Whitney, J. D. *Mining Magazine*, N. Y. 1856., vii, pp. 67-73. Considered iron ores of Lake Superior and other regions as of eruptive origin.

——. *Iowa Geological Report*. 1858.

Whittlesey, Col. Chas. *Proc. A. A. A. S.* 1867. p. 98.

"About five hundred miles north of the iron mountains of Missouri, on the waters of Lake Superior, occur the iron mountains of Michigan and Wisconsin. Those in the latter state occupy a belt about thirty miles in length, extending south-westerly from the boundary on Montreal river, at a distance of ten to twenty miles from the lake. This ore is *wholly magnetic* and occurs as a stratum, in a belt of stratified azoic quartz, dipping, north-westerly, at a high angle beneath the copper-bearing trap."

"Thus the notable deposits of magnetic and specular iron ore are found associated with the quartz rocks, hornblende rocks, porphyry, micaceous schists and dolomitic marbles, composing the most ancient metamorphic series. If the metamorphism of the Laurentian and Huronian formations shall be regarded as an established geological fact, the separation of the oxides of iron from these rocks into veins, beds and masses can be easily accounted for. All sedimentary strata contain the oxides of iron; and any agent powerful enough to change the crystalline form of rock would bring about a concentration of their minerals. Metals, their oxides and salts, possess an inherent quality of segregation. Whenever the condition of the enclosing strata is such as to allow of motion among particles having the affinity of segregation, they must obey this affinity and become more concentrated." (l. c. p. 101.)

Still again we find, l. c. p. 107.

"But more recent investigations show that hematite is not necessarily of sedimentary origin. Hydrates are common in rocks which are still regarded as igneous.

Throughout the masses of specular ore in Marquette county, Michigan, are large bunches of hematite, so extensive as to form a material part of the ore now mined. Hematites are too extensive and too far below the surface to admit a general theory of recent and more local changes.

Depth has disclosed no modifications in the ores of the Green mountains; and since these beds were subject, on account of their softness, to great destruction by the drift forces, the bottom of the present mines, in some places more than one hundred feet down in ore, must be regarded as much more than that distance below the original surface. The causes which concentrated the ore along this line of several hundred miles, everywhere in contact with metamorphic limestone, must have been universal and not local. Iron in some form exists in all rocks. The limestone beds of the Clinton and Hudson river groups are charged with it, especially near their junction, where the oolitic or dye-stone ore is generally found. If these strata should undergo a molecular change, whatever the agent might be, it must act, at the same time, as a concentrator of their mineral contents. In this action limestone seems to be an almost necessary medium or facilitator. The belief in a wide spread, almost an universal, metamorphism of the rocks is rapidly gaining ground. In this mysterious but acknowledged force, which produces a new crystalline arrangement, have we not all the required agencies to produce masses of any mineral which existed in the strata prior to the change? Is not something more necessary to account for the results—some cause more universal than local chemical action?"

Whittlesey, Charles. On the Origin of the Azoic Rocks of Michigan and Wisconsin. *Proc. Am. Assoc. Adv. Sci.*, 1859, xiii, 301-308.

———. The Penokie Mineral Range, Wisconsin. *Proc. Bost. Soc. Nat. Hist.*, 1863, ix, 235-244.

———. Physical Geology of Lake Superior. *Proc. Am. Assoc. Adv. Sci.*, 1875, xxiv, 60-72.

———. On the Origin of Mineral Veins. *Proc. Am. Assoc. Adv. Sci.*, 1876, xxv, 213-216.

"My object will be to show that electricity in some of its manifestations, may be regarded as the principal agent, or force, which accomplishes the filling of veins. I shall use this term in its general sense, to cover galvanism, electro-magnetism and all other modes of electrical action. * * * The term fissure, or fissure-vein will also be used generically; embracing balls, vugs, stock-works, floors and bunches, as well as true veins."

———. Iron Ores of the Great Seam Coal Region. *Cleveland*, 1877.

Wichmann, A. *Geol. Sur. Wis.*, vol. iii. 1880.

Willecock, J. On the History, Progress and Description of the Bowling Ironworks. *Rep. Brit. Assoc. for 1873*, sections, pp. 219-222.

"The geology around Bowling and the character of the coal-seams and ironstone are described."

Williams, J. J. The Mineral Resources of Flintshire and Denbighshire. *Trans. N. Engl. Inst. Eng.*, vol. xxv, pp. 81-100. 1876.

Williams, W. M. Iron and Steel Manufacture. Lecture 1, *Journ. Soc. Arts*, vol. xxiv, No. 1234, p. 827. 1876.

Winchell, Alexander. *Rep. Geol. Sur. Mich.*, 1870. pp. 26, 27.

"The rich masses of magnetic and hematitic ores of iron are found not to be those erupted outbursts which the older geologists were inclined to regard them. They are simply constituents of the system of sedimentary deposits which make up the Huronian system of Michigan."

———. Sixteenth Annual Report Geological and Natural History Survey of Minnesota. 1887. p. 367.

"As to the eruptive origin of the hematites and associated jaspilites, the evidences of it are so slender that the doctrine would only excite my wonder, if it were not held by a few geologists of good reputation. The difficulties of that view are many, but I must embrace another occasion to set them forth."

———. Recent Observations on some Canadian Rocks. *Am. Geol.*, vol. vi; Nos. 5, 6. 1890. Describes hematite occurring in true veins with walls of quartzite or in connection with diorite dykes.

Winchell, N. H. Geological and Natural History Survey of Minnesota, Fifteenth Annual Report. 1886. Origin of the iron ore and jaspilite of the Keewatin is treated of in pages 223-247. The eruptive theory is discussed but not adopted. Suggests that the hematites may have been formed by a substitution of iron oxide for lime carbonate.

Winchell, N. H. and H. V. On a possible chemical origin of the iron ores of the Keewatin in Minnesota. *Am. Geol.*, vol. iv. No. 5. 1889., pp. 291-300; vol. iv, No. 6, pp. 392-395; A. A. A. S. 1889.

Winchell, H. V. The Diabasic Schists containing the jaspilyte beds of northeastern Minnesota. *Am. Geol.*, vol. iii, No. 1. 1889. pp. 19-22.

Wilson, Daniel. The Southern Shores of Lake Superior. *Canad. Jour.*, 1856, (2.), i, 344-356.

Wohler, F. [Greenland Native Iron.] *N. Jahrb.*, pp. 832-834. 1879.

Wolff, G. *Zeitschr. d. d. geol. Gesellsch.* 1877. Bd. 29, p. 149.

Wood, W. M. Mineral Deposits in Southern States of America. *Jour. Soc. Arts*, vol. xxxii, No. 1646, pp. 734, 735. 1884.

Woodward, H. B. Geology of East Somerset and the Bristol Coal-fields. Pp. x, 271, 9 plates. *Geological Survey Memoir.* 8vo. London. 1876.

Wright, Chas. E. 1st Annual Report Commissioner Mineral Statistics of Michigan. 1879. p. 15.

"In these mines it appears that the finely divided silica has been more or less dissolved out by alkaline thermal water, leaving the iron oxide and other bases behind. He regards the ores of sedimentary origin.

———. Annual Report of Commissioner of Mineral Statistics of Michigan, 1881, pp. 153-230.

———. Annual Report of Commissioner of Mineral Statistics of Michigan, 1880, pp. 162-250.

Wright, C. R. Alder. *Encyclopædia Britannica*, Ninth Edition, vol. xiii, pp. 286, 287. In the article on "Iron":

"Hæmatitic ores are usually found in the older geological formations, especially the Huronian, Cambrian, Silurian, Devonian and Carboniferous rocks; in many cases they are of distinctly sedimentary character, *i. e.*, they have obviously been deposited by aqueous agency. Some deposits have probably been originally thrown down either as ferric oxide detritus from the abrasion of rocks, etc., containing ferruginous matter, or as hydrated oxide from the oxidation of water containing ferrous carbonate in solution, the ochreous deposits thus formed having been rendered more or less completely anhydrous and indurated by the long-continued effect of pressure and the conduction of the internal heat of the earth to them. The Cumberland hæmatite largely occurs in pockets in Carboniferous limestone, and has doubtless been produced by the latter kind of agency, the cavities of the limestone rock becoming gradually filled up by the deposition of iron oxide. Red sandstones, on the other hand, represent deposits of ferric oxide thrown down simultaneously with much sand; whilst the earthy varieties of hæmatite have probably been less indurated by heat and pressure, and were doubtless formed by deposition from water containing clayey matters in suspension to a greater or less extent. The Alabama deposits exhibit distinct stratification, forming a bed between the Coal Measures and the Devonian Limestone upwards of 100 feet in thickness, and several square miles in extent. In Cornwall, North Wales, and especially in the Lake Superior and Missouri districts, the hæmatitic deposits form large veins and lodes. The specular ores of Elba, Sweden, Missouri and elsewhere usually occur as massive deposits; portions of the latter occasionally show the passage of spathose ore into specular ore (Snelus), suggesting the effect of heat accompanied by oxidizing action. Occasionally brown hæmatite is found passing into red, indicating gradual dehydration more complete in one portion of the deposit than in another. Many deposits (of brown hæmatite) have been apparently formed by the alteration of argillaceous ferrous carbonate; others from superficial sandy beds, produced by the deposition of ochreous matter from solution either by purely chemical action, such as the oxidation of dissolved ferrous carbonate, or by the action of organized beings, especially Diatomaceæ. Usually brown hæmatites are distinctly of sedimentary character, forming beds; but they often occur also as veins, especially in the older formations, doubtless deposited (often along with other minerals *e. g.* copper ores) from water flowing through the cracks and crevices of the rocks."

———. Metals and their Chief Industrial Applications.

Wurtenberger, ———. *Neues Jahrb. f. Mineral.* 1867, p. 685.

Wurzbürger, P. On the Geology of the North Lancashire and Cumberland Iron-ore Districts. *Journ. Iron Steel Inst.*, No. 2, 1874, pp. 287-296.

The Hematite deposits occur as veins in the Lower Silurian, but are both larger and purer in the Mountain Limestone—as "flat deposits which follow more or less the dip," as veins, and filling irregular hollows.

Wyley, Andrew. The Iron Industries of Upper Austria. *Proc. Dudley Geol. Soc.*, vol. 3, No. 3, pp. 45-47. 1877.

Zaytzev, A. [Preliminary account of geological researches in the Urals, made in 1885.] *Bull. Com. Géol.*, No. 2, pp. 57-85.

———. [Geological description of the region of the Revdinsk and Werkhné-Issete forges and their environs.] *Mém. Com. Géol.*, T. iv., No. 1, pp. 1-140. 1886.

———. [Preliminary account of geological investigations in the Urals in 1887.] *Bull. Com. Géol.*, No. 7, pp. 263-288. 1888.

Zemiatschensky, P. [The iron ores of Central Russia.] *Trav. Soc. Natur. St. Petersburg*. Vol. xx, pp. 1-306, plate. 1889.

"Part three considers the age and the origin of the ores. The author is driven to the following conclusions: All the minerals of the region studied are simply sphaerosiderite and limonite, the latter being always (?) of secondary origin, arising from the decomposition of the sphaero-siderite. All (?) the minerals are directly allied with the various limestones, and have been produced by the action of iron solutions on calcareous rocks. Some of the limestones are dolomitic. Hydrochemical processes which have given rise to these iron minerals are manifest through a whole series of geological periods, and have been of various durations. There are some which are still active at present."

Zepharovich, ——— v. *Neues Jahrb. f. Miner.* 1865, p. 50; 1867, p. 715, and 1870, p. 355.

Zerrenner, ———. *Zeitschr. d. d. geol. Gesellsch.* Bd. I, 1849, p. 475.

Zimmermann, ———. Die Wiederausrichtung verworfener Gänge, Lager und Flotze. *Darmstadt und Leipzig*, 1828.

———. Das Harzgebirge, 1834, p. 98.

Zimmerman, C. F. Ober-Sächsische Bergakademie. *Dresden*. 1746.

Zimmermann, ———. In *Karsten's Arch.*, 1837, vol. x, p. 26, Iron Ore deposits of the Hartz are described.

Zinken, ———. Der östliche Harz, vol. i, p. 135. 1825.

Zirkel, ———. *Petrographie*. I. 1866, p. 341.]

Zouloukidze, G. [Geological researches in the region of the Alguetka and Khrama valleys.] *Mat. Géol. Caucase*. Sér. II, livr. 1, pp. 1-70. 1886.

PART VI.

LIST OF COMPANIES INCORPORATED UNDER THE LAWS OF MINNESOTA FOR THE PURPOSE OF MINING AND QUARRYING.

[The name of the company is stated first, then the place of its principal office, amount of capital stock, number of shares, date of incorporation, and names of incorporators in order. This list is complete up to Dec. 1, 1890.]

Abacus Iron Mining Company; St. Paul; \$1,000,000; 10,000 shares; March 31, 1887. A. D. McLeod, G. C. Olcott, W. R. King, W. N. Viguers.

A. E. Maher Mining, Smelting and Milling Company; St. Paul; \$20,000; 400 shares; Nov. 19, 1888. A. E. Maher, P. H. Rasche, W. H. Hopson.

Alaska Treadwell Gold Mining Company; St. Paul; \$5,000,000; 200,000 shares; Nov. 21, 1889. J. A. Humphreys, S. E. Day, W. H. Williams.

Algoma Gold and Silver Mining Company; Minneapolis; \$2,000,000; 200,000 shares; May 5, 1888. O. N. Murdock, A. D. Dunn, F. J. Bletcher, A. J. Olmsted, H. J. G. Croswell, G. H. Browne, R. R. Knapp, E. E. McDonald.

Anchor Iron and Smelting Company; Minneapolis; \$1,500,000; 60,000 shares; Aug. 29, 1887. J. F. Force, B. Cloutier, L. Matthews, F. Murdock, R. E. Trafton.

Ancient Diggings Company; Cook county, Minn., and Detroit, Mich.; \$1,000,000; 40,000 shares; May 23, 1885. W. P. Spalding, T. S. Sprague, C. J. Hunt, W. F. Eberts, H. S. Sprague.

Arizona Northern Mining Company; Minneapolis; \$75,000; May 22, 1880. J. Barry, A. Kelly, P. H. Kelly, W. W. McNair, J. K. Sidle, G. H. Christian, G. H. Keith, W. D. Hall, T. S. King, R. J. Baldwin.

Arrow River Mining and Manufacturing Company; Minneapolis; \$2,500,000; 250,000 shares; Aug. 20, 1884. W. W. Braden, J. H. Baker, J. McGuire, S. Leavitt, F. P. Lane.

Ashland Iron and Steel Company; Minneapolis; \$250,000; 2,500 shares; Oct. 18, 1886. J. E. York, A. H. Linton, R. B. Langdon, C. L. Langdon, H. C. Henry, W. W. Eastman, J. H. Clarke, W. J. Van Dyke.

Avalanche Mining Company; Verndale; \$500,000; 50,000 shares; April 5, 1886. E. S. Case, E. K. Nichols, H. A. Thompson, A. F. Stewart, T. Tinkelpaugh.

Bald Mountain Mining Company; Minneapolis; \$2,500,000; 100,000 shares; April 12, 1884. R. S. Innes, R. D. Russell, G. B. Kirkbride, S. P. Snider.

Beaver Bay Mining Company; Duluth; \$1,000,000; 200,000 shares; March 25, 1885. E. R. Jefferson, E. C. Howard, B. G. Segog, J. A. Stockbridge, C. E. Wheeler.

Bed Rock Iron Mining Company; Minneapolis; \$600,000; 60,000 shares; Aug. 10, 1887. L. N. Sharpe, N. S. Lockwood, C. E. Case, E. O. Cosman, E. B. Peaslee, A. H. Noyes, B. F. Teall.

Belle Plaine Salt Company; Belle Plaine; \$15,000; 300 shares; Aug. 16, 1872. S. A. Hooper, S. A. Packer, R. H. Rose, A. G. Chatfield, M. M. Carson, C. T. Metzener, H. B. Gates, W. T. Woods, I. P. Black.

Ben Harrison Gold and Silver Mining Company, of Granite Falls, Minnesota; Granite Falls; \$125,000; 5,000 shares; Dec. 5, 1888. S. F. Scott, W. N. Allen, O. S. Richards, J. M. Thompson, M. Campbell, G. Powers.

Biwabik Mountain Iron Company; Duluth; \$2,000,000; 20,000 shares; Oct. 9, 1890. L. Merritt, E. H. Hall, J. J. Wheeler.

Bishop Iron Company; Chicago, Ills.; \$1,000,000; 40,000 shares; March 28, 1889. J. C. Sterling, R. Forsyth, C. W. Hillard.

Black Hawk Land and Mining Company; Glencoe; \$100,000; 20,000 shares; May 17, 1890. H. B. Strait, C. T. Buchanan, J. A. Collier, J. C. Buchanan, G. K. Gilbert, R. Buchanan, M. T. Gitchell, L. W. Gilbert, C. H. Silvers.

Black Hills Tin Mining Company; St. Paul; \$1,000,000; 200,000 shares; April 18, 1888. R. J. Truax, J. McNamara, S. J. Truax, J. A. Southall, J. A. Smith, C. Madden, J. L. Fox, J. Mory, N. L. Bailey, *et al.*

Blair Manganese Mining Company; Minneapolis; \$125,000; July 24, 1888. T. E. Penney, F. E. H. Bruen, J. B. Shoenfelt, G. B. Shoenfelt.

Boston Iron Mining Company; Minneapolis; \$1,000,000; 40,000 shares; Jan. 29, 1887. E. J. Shaw, G. W. Payne, E. A. Sumner.

Brazil Iron Mining Company; St. Paul; \$1,000,000; 40,000 shares; June, 25, 1887. M. D. Miller, N. P. Frost, B. F. Wright, J. D. Bisbee.

Bristol Silver Mining Company; Minneapolis; \$50,000; Dec. 19, 1879. G. H. Keith, R. J. Baldwin, F. A. Lewis, J. B. Crooker, G. B. Mead, W. S. King, H. M. Goodhue, M. W. Lewis.

Brookfield Mining Company; Duluth; \$500,000; 50,000 shares; Feb. 9, 1887. W. O. Hughart, Jr., J. D. Howard, J. D. Ensign, D. G. Cash, A. J. Whiteman.

Cabinet Consolidated Mining Company; Minneapolis; \$1,500,000; 150,000 shares; Aug. 30, 1883. C. C. Hughes, J. C. Howard, J. A. Leach, D. B. Burdette, E. C. Stewart, J. F. Reed, W. C. Tonkin.

Cambria Mining, Milling and Smelting Company; St. Paul; \$1,000,000; 100,000 shares; Aug. 21, 1884. J. Edwards, N. M. Singleton, F. B. Howell, J. K. Stone, R. W. Cavanaugh.

Canon Iron Company; Chicago, Ill.; \$50,000; 2,000 shares; April 13, 1889. R. Spencer, A. C. Ely, J. H. Chandler.

Carbonette Mining and Milling Company; Black Hawk, Col.; \$1,000,000; 200,000 shares; Sept. 14, 1887. C. M. McLain, A. B. Roberts, J. Owens.

Carlotta Gold Mining Company; St. Paul; \$1,000,000; 100,000 shares; March 20, 1885. J. S. Prince, G. Mitch, R. W. Johnson, A. Allen, E. H. Strong, N. H. Hemiup.

Carleton Land, Mineral and Mining Company; Duluth; \$100,000; 2,000 shares; Aug. 29, 1890. H. J. Jewett, H. B. Payne, H. M. Rice, J. Wade S. T. Everett.

Central Iron Mining Company; Minneapolis; \$1,000,000; 100,000 shares; May 20, 1887. J. C. Joslyn, W. P. Buell, D. A. Pool, G. C. Card, C. S. Sedgwick, C. W. Betts, J. Lucas, C. P. Beard.

Champion Iron Company; Duluth; \$1,000,000; 40,000 shares; March 2, 1889. J. I. Gilbert, W. McRae, C. F. Howe.

Candler Iron Company; Duluth; \$1,000,000; 40,000 shares; May 2, 1887. J. H. Chandler, J. H. James, H. J. Pickands, J. C. Morse, A. C. Ely.

Chengwatona Mining Company; St. Paul; \$100,000; 4,000 shares; Nov. 11, 1880. J. P. Ilsley, J. B. Smith, J. F. Ilsley, J. J. Porter, J. Smith, Jr.

Chippewa Iron Company; Chicago, Ills.; \$1,000,000; 40,000 shares; April 13, 1889. R. Spencer, A. C. Ely, J. H. Chandler.

Clyde Iron Company; Duluth; \$100,000; 1,000 shares; Oct. 24, 1889. C. P. Craig, James Cash, J. W. Anderson, D. G. Cash, J. G. Williams.

Coleman Mining Company; Winona; \$2,500,000; 100,000 shares; Sept. 20, 1881. W. F. Phelps, H. D. O'Neill, C. H. Berry, C. L. Bonner, P. Hueffner, C. Doud, R. F. Doud.

Colville Mining Company; St. Paul; \$1,500,000; 300,000 shares; Nov. 12, 1887. W. D. Stearns, H. E. Goodrich, W. E. Monroe.

Consolidated Clancy Creek Mining Company; Minneapolis; \$2,500,000; 100,000 shares; April 12, 1884. S. H. Baker, W. H. Eastman, S. P. Snider.

Consolidated Vermilion Iron and Land Company; Duluth; \$1,000,000; 100,000 shares; May 12, 1887. R. S. Munger, J. T. Hale, D. G. Cash, J. M. Smith, F. A. Day, G. W. Kimberly, H. W. Coffin, A. P. House, C. F. Dickerman, S. W. Matteson.

Crescent Iron Mining Company; Duluth; \$200,000; \$40,000 shares; Feb. 13, 1890. J. McKinley, C. E. Shannon, J. H. James, J. Shephard, J. G. Brown.

Crested Butte Mining and Smelting Company; St. Paul; \$250,000; 50,000 shares; Dec. 18, 1883. B. Beaupre, D. Ryan, F. Keogh, J. C. Meloy, I. E. Finch.

Crown Point Mining Company; Minneapolis; \$2,500,000; 100,000 shares; April 12, 1884. R. S. Innes, A. J. Trimble, S. P. Snider.

Crown Point Mining Company; Duluth; \$600,000; 60,000 shares; May 31, 1890. A. D. Cummings, H. R. Tinkham, E. Tinkham, Hillyer, G. A. Elder, J. Billings, C. E. Shannon, J. Bond, Jr.

Dakota Gold Mining Company; Minneapolis; \$300,000; 10,000 shares; June 16, 1880. J. P. Wilson, S. A. Reed, M. A. Larson, M. Aspland, L. L. Baxter.

Dakota Iron and Steel Company; Minneapolis; \$750,000; 15,000 shares; May 4, 1886. W. Baker, E. R. Kent, R. B. Mumford.

Dakota Mining Company; Minneapolis; \$100,000; 10,000 shares; April 14, 1880. J. Anderson, S. A. Reed, M. A. Larson, M. Aspland, R. L. Baxter.

Delaware Iron Company; Chicago, Ill.; \$50,000, 2,000 shares; April 13, 1889. R. Spencer, A. C. Ely, J. H. Chandler.

Derwood Consolidated Mining and Milling Company; St. Paul; \$5,000,000; 500,000 shares; Dec. 14, 1888. J. A. McKinley, J. A. Brent, W. B. Sparkman, J. W. Erwin, F. F. Ellis, T. H. Monahan.

Defective Mining Company; Minneapolis; \$2,500,000; 100,000 shares April 19, 1888. F. J. Drew, J. H. Wheeler, J. A. Northrop, C. S. Northrop.

Duluth and Nova Scotia Mining Company; Duluth; \$1,000,000; 100,000 shares; Dec. 8, 1886. H. Burg, M. Haug, C. Poirier, H. F. Miller, M. Fink.

Duluth Brown Stone Company; Duluth; \$30,000, 600 shares; March 31, 1887. J. H. Crowley, A. McDougall, F. B. Lazier.

Duluth Gold and Silver Smelting and Refining Company, Duluth; \$100,000, 1,000 shares; Aug. 18, 1887. H. H. Hawkins, J. H. Triggs, F. E. Kennedy, J. B. Sutphin, L. W. Young.

Duluth Iron Company; Duluth; \$100,000, 4,000 shares; Nov. 19, 1879. D. M. Sabin, C. H. Graves, G. Spencer, J. Ilsley, C. F. Cruft.

Duluth Iron Mining and Development Company; Duluth, \$1,000,000, 100,000 shares, Nov. 19, 1886. S. Chapman, G. C. Greenwood, J. H. James, J. Sheridan.

Duluth Mineral Land Company; Duluth; \$35,000, 1,400 shares; Dec. 27, 1884. W. C. Sargent, H. C. Kendall, E. V. Mundy, W. Bunnell, H. B. Moore, J. Rice, A. Fraser.

Duluth Mining and Smelting Company; Duluth; \$1,000,000, 10,000 shares; Jan. 11, 1887. R. S. Munger, J. D. Ensign, A. N. Seip, J. R. Myers, O. N. Simonds.

Duluth Mining Stock Exchange; Duluth; \$500,000, 10,000 shares; March 28, 1887. F. W. Eaton, R. H. Fagan, N. B. Thayer, H. H. Bell, J. Fraser, J. B. Sutphin, J. W. Anderson.

Duluth Natural Gas, Oil and Mineral Company; Duluth; \$100,000; 1,000 shares; Aug. 10, 1887. W. A. Foote, J. D. Ray, J. R. Carey, L. Mendenhall, J. H. Triggs, N. J. Miller, S. E. Cheeseman.

Duluth Silver and Copper Mining Company; Duluth; \$200,000; 100,000 shares; Dec. 10, 1883. H. A. Douglas, B. Brown, C. Markell, M. Daniels, H. W. Pearson, M. Fink, H. H. Bell.

Eagle Mining Company; St. Paul; \$1,000,000; 100,000 shares; June 16, 1882. F. Beebe, J. A. Conlee, J. M. Gilman, C. Eaton.

East Hoppenyan Iron Mining Company; Minneapolis; \$1,000,000; 40,000 shares; Oct. 4, 1887. J. Paulson, E. Farnsworth, Jr., W. P. Andrus, O. J. Nevitt, W. A. Hemphill, M. FitzSimmons, S. H. Soule.

Eden Prairie Mining Company; Minneapolis; \$1,000,000; 10,000 shares; Jan. 14, 1889. R. J. Anderson, E. U. Loose, D. A. Fisk.

Ellsworth Consolidated Mining Company; St. Paul; \$1,000,000; 200,000 shares; Nov. 1881. A. DeGraff, E. S. Goodrich, R. Knapp.

Enterprise Iron and Lead Company; Duluth; \$50,000; 2,000 shares; Dec. 21, 1889. J. Frank, E. Hartmann, L. Moss, L. Minzesheimer, D. Goodman.

Equator Mining Company; Minneapolis; \$10,000,000; 200,000 shares; Nov. 11, 1887. T. B. Stone, E. B. Burdick, J. E. Merritt, J. W. Griffin.

Fayal Iron Company; Chicago, Ills.; \$50,000; 2,000 shares; April 13, 1889. R. Spencer, A. C. Ely, J. H. Chandler.

Flag River Brown Stone Company; Duluth; \$30,000; 600 shares; Jan. 29, 1889. J. F. Fredin, A. Broman, F. H. Quinby, C. W. Wilson, G. J. Miller, S. J. Miller.

Florella Mining Company; Minneapolis; \$10,000; 200 shares; Dec. 29 1884. C. P. Cole, A. Y. Merrill, A. W. Stow.

Florence Mining and Smelting Company; St. Paul; \$100,000; 4,000 shares; Dec. 24, 1878. C. W. Carpenter, D. A. Montfort, C. Eaton, C. S. Mine, W. Dawson, R. A. Smith, N. W. Kittson, J. J. Hill.

Freeborn Consolidated Coal Mining Company; Alden; \$40,000; 1,600 shares; Feb. 14, 1882. E. G. Clark, E. G. Perkins, W. W. Cargill.

French River Mining Company; Duluth; \$100,000; 2,000 shares; Aug. 16, 1863. R. T. Paine, H. B. Paine, R. B. Carlton, E. Goodrich, G. L. Becker.

Galena Silver Mining and Milling Company; St. Paul; \$1,000,000; 200,000 shares; March 22, 1887. A. M. Levy, C. E. Fowler, H. H. Hamilton, C. M. McLain, J. Q. Haas.

Garden Lake Mining Company; Duluth; \$1,000,000; 40,000 shares; July 7, 1888. F. Hibbing, R. D. Mallet, E. Hartmann, F. W. Smith, W. Marshall, S. Clark, C. H. Eldridge, F. B. Spelman, *et al.*

Germania Iron Company; Duluth; \$50,000; 500 shares; June 4, 1889. E. Hartmann, W. W. Billson, E. C. Little.

Gitchegumee Gold and Silver Mining Company; Minneapolis; \$2,000,000; 200,000 shares; May 7, 1888. A. F. Olmsted, H. J. G. Croswell, O. N. Murdock, T. J. Bletcher, J. Kaufman.

Gogebic Bessemer Ore Company; Minneapolis; \$5,000,000; 200,000 shares; Feb. 14, 1890. W. Pond, J. N. Cross, F. H. Carleton, N. M. Cross.

Gogebic Development Company; Minneapolis; \$5,000,000; 200,000 shares; April 26, 1887. S. P. Snider, J. W. Pence, A. J. Trimble, S. E. Neiler, T. J. Buxton, M. L. Hallowell Jr., A. H. Hall.

Gogebic Prize Iron Mining Company; St. Paul; \$800,000; 80,000 shares; June 9, 1887. H. Laycock, A. B. Roberts, H. W. Knapp, O. A. Turner, W. B. Stephens.

Gold Hill Mining Company; Minneapolis; \$5,000,000; 200,000 shares; May 28, 1886. D. B. Burdette, J. B. Collins, J. K. Wright, G. F. Jackson, N. C. Tomkins.

Gold Hunter Mining and Smelting Company; St. Paul; \$2,000,000; 200,000 shares; Feb. 2, 1887. D. Ryan, P. T. Kavanaugh, R. B. Galusha, P. M. Hennessy, B. A. Cox.

Gold King Mining and Milling Company; Denver, Col., and St. Paul; \$750,000; 150,000 shares; Dec. 30, 1885. C. A. Heffelfinger, A. M. Levy, F. P. Lane, F. Cramer, G. Canfield.

Gold River Mining Company; Duluth; \$500,000; 50,000 shares; June 25, 1887. J. D. Ensign, O. P. Stearns, H. A. Smith, J. B. Howard.

Gopher Gold and Silver Mining Company; Minneapolis; \$100,000; 100,000 shares; July 28, 1890. J. W. Griffin, L. Swift, Jr., J. R. Jones, H. A. Turner, R. Blaisdell, A. F. Olmsted.

Grand Mara's and Vermilion Iron and Land Company; St. Paul; \$2,000,000; 80,000 shares; Dec., 1887. G. M. Smith, C. T. Dunbar, A. Delaney, J. E. McWilliams, J. F. Van Sickle, R. W. Cavanaugh, T. W. Kennedy, E. C. Dunn, *et al.*

Granite Falls Stone Quarry Company; Granite Falls; \$10,000; 1,000 shares; Sept. 5, 1887. J. G. Dodsworth, W. W. Penney, K. E. Neste, C. J. Goodenow; D. A. McLarty.

Great Western Mining Company, of Pennsylvania; \$5,000,000; 500,000 shares; Jan. 26, 1870. T. S. Emery, S. Knapp, G. Sturges, G. B. Fitts, W. Rallen.

Hall Iron Mining Company; Duluth; \$500,000; 20,000 shares; Jan. 10, 1888. F. H. Frisbee, J. A. Hall, G. C. Howe, P. M. Graff, F. L. Murray.

Ham's Fork Coal Mining Company; \$2,500,000; 100,000 shares; Dec. 8, 1884. O. J. Johnson, H. Brintnell, J. W. Cochran, H. N. Anderson, H. C. Peterson, P. P. Swenson, H. Church, A. A. Bailey, I. C. Winslow.

Hartmann-Mallet Iron and Land Company; Duluth; \$1,500,000; Dec. 1, 1888. E. Hartmann, R. D. Mallet, J. T. Hale.

Hawkeye Mining Company; St. Paul; \$2,500,000; 100,000 shares; May 24, 1880. J. A. Hughes, Jr., R. P. Hughes, S. Newell, R. Merriam, H. B. Willis, G. B. Young.

Hekla Iron Mining Company; St. Paul; \$1,000,000; 40,000 shares; March 11, 1887. F. M. Morris, H. B. Watson, H. B. Norville, H. C. Masters, H. J. Overholzer, O. J. Nevitt, C. B. Walker, C. C. Greeley, *et al.*

Hematite Iron Company; Duluth; \$1,000,000; 40,000 shares; July 27, 1887. J. B. Sutphin, J. C. Clark, H. C. Kendall, F. W. Eaton, H. A. Blume, O. W. Traphagen, F. N. Parcher.

Hennepin Mining Company; Minneapolis; \$2,500,000; 250,000 shares; March 3, 1887. E. J. Davenport, G. D. Emery, J. V. Nye.

Hidden Treasure Gold Mining Company; St. Paul; \$5,000,000; 500,000 shares; Dec. 19, 1887. D. C. Price, L. D. Hause, J. C. Oabanne, W. Wilkin, J. Phillips, R. F. Hersey, E. L. Hersey, W. W. Price.

Higgins Wildcat Company; Duluth; \$2,000,000; 2,000 shares; March 3, 1890. W. H. Butler, O. T. Higgins, F. R. Webber, C. D'Autremont, G. Gilbert, W. H. Acker, F. W. Higgins, H. C. Morgan, *et al.*

Home Gold and Silver Mining Company, of Wabasha; \$500,000; 10,000 shares; March 19, 1865. W. T. Dugan, J. F. Rose, D. H. Eldridge, O. J. Noble, S. Wells, E. S. Wills, J. H. Mullen.

Home Iron Mining Company; Duluth; \$1,000,000; 40,000 shares; Dec. 13, 1887. R. N. Marble, J. Flynn, E. Hartmann, R. D. Mallet, H. R. Harvey.

Home Mining Company, Duluth; \$1,500,000; 150,000 shares; April 10, 1885. J. D. Ensign, D. G. Cash, C. F. Bay, J. Kajander.

Hope Iron Land Company, Chicago, Ill.; \$25,000; 1,000 shares; Dec. 21, 1889. L. Silverman, J. Frank, E. Hartmann, L. Moss, L. F. Minzesheimer.

Ida C. Mining and Milling Company, Minneapolis; \$500,000; 250,000 shares; Aug. 22, 1889. W. H. Middlemist, M. N. Price, A. D. Westby.

Imperial Gold Mining Company, Minneapolis; \$1,250,000; 125,000 shares; April 27, 1885. R. W. Johnson, W. Baker, E. H. Strong, J. H. Baker, N. H. Hemiup.

Iron Dollar Silver Mining Company, St. Paul; \$2,500,000; 250,000 shares; Sept. 12, 1887. J. H. Mahler, E. F. Mues, C. T. Newcomb, C. W. Eberlein, J. R. Foulke, J. E. Sherin, A. Donald.

Iron Ore Mining Company, Minneapolis; \$1,000,000; 40,000 shares; April 19, 1887. E. W. Hand, M. V. Little, F. H. White, E. J. Swan.

Iron River Brown Stone Company, Duluth; \$100,000; 2,000 shares; Feb. 27, 1890. J. F. Fredin, C. W. Wilson, J. F. Gargill, B. L. Peterson, A. Broman.

Iron-ton Steel Company, Duluth; \$1,000,000; 10,000 shares; Aug. 20, 1890. F. Barrett, G. A. Atkins, F. B. Williams, J. J. Sullivan, J. L. Wylie, C. W. Boyd, W. Duffey, J. J. Bright, J. P. Morrow.

Jefferson Silver Mining Company, St. Paul; \$500,000; 100,000 shares; Oct. 26, 1882. A. De Graff, L. D. Hodge, E. S. Goodrich.

Jordan Mining Company, Jordan; \$250,000; 2,500 shares; Dec. 8, 1887. F. Nicolin, H. Nicolin, W. W. Knott, C. Erickson, P. Rich, J. H. Nicolin, H. Hartwig, M. M. Shields, F. Nicolin, Jr., *et al.*

Judith Mining Company; St. Paul; \$100,000; 1,000 shares; May 22, 1885. A. DeGraff, E. N. Saunders, S. S. Eaton, H. L. Moss, W. S. Alexander.

Kakabeka Gold and Silver Mining Company; Minneapolis; \$2,000,000; 200,000 shares; May 5, 1888. C. Sunderland, A. C. Dunn, F. J. Bletcher, O. N. Murdock, H. M. Murdock, R. R. Knapp, E. E. McDonald.

Kaministiquia Iron Mining Company; St. Paul; \$2,500,000; 100,000 shares; Dec. 14, 1887. O. N. Murdock, W. Murdock, V. Bowerman, A. F. Olmsted, G. M. Smith, E. E. McDonald.

Kettle River Sandstone Company; St. Paul; \$250,000; 5,000 shares; Sept. 16, 1887. W. H. Grant, J. P. Knowles; J. Hurley, F. A. Hodge.

Lake Iron Mining Company; St. Paul; \$1,000,000; 40,000 shares; March 12, 1887. F. M. Ferris, J. D. Cameron, R. G. Baldwin, C. Martin, W. S. Reynolds, C. B. Walker, W. McDonald, C. B. Harvey, *et al.*

Lehigh Coal and Iron Company; St. Paul; \$500,000; 5,000 shares; April 30, 1886. C. W. Griggs, A. G. Foster, J. L. Lewis, A. G. Yates.

Lincoln Silver Mining Company; Minneapolis; \$200,000; ———— shares; Oct. 26, 1880. W. Windom, C. C. Jones, C. M. Loring, R. S. Jones, H. M. Goodhue, G. J. Goodhue, A. C. Loring, G. L. Scott, J. E. Miner.

Lochiel Iron Mining Company; St. Paul; \$1,000,000; 100,000 shares. July 25, 1887. P. H. Rasche, C. C. Fairchild, W. J. O'Brien, J. F. Heinlein, C. H. VanAuken.

Lone Hand Mining Company; St. Paul; \$1,500,000; Aug. 6, 1887. H. B. Willis, H. P. Hall, E. W. Johnson, E. L. Corning, C. C. Perkins, J. M. Gilman.

Longyear Mesaba Land and Iron Company; Jackson, Mich.; \$500,000; 20,000 shares; Dec. 10, 1887. J. M. Longyear, J. M. Case, C. C. Bloomfield, A. B. Robinson, D. S. Smith, H. H. Smith, Henry H. Smith, W. H. Withington, A. M. Walker, *et al.*

Lumberman's Mining Company; Stillwater; \$1,000,000; 40,000 shares; May 28, 1887. C. E. Mosier, L. Clarke, C. Conham, E. J. Rowly, R. Fitzgerald, J. A. Abraham, W. P. Brown.

Luverne Granite Company; Luverne; \$200,000; 2,000 shares; Feb. 13, 1886. B. C. Richards, C. H. Wynn, B. L. Richards, C. A. Wynn.

Macomber Mining Company; Duluth; \$1,000,000; 100,000 shares; Dec. 5, 1888. J. A. Willard, G. F. Piper, M. G. Willard, C. Markell, H. W. Coffin, C. E. Shannon, A. L. Warner, W. C. Sherwood, T. B. Mills.

Madison Mining and Reduction Company; Minneapolis; \$1,000,000; 10,000 shares; Aug. 12, 1887. J. B. Atwater, A. B. Jackson, G. C. Ripley, C. K. Davis, E. S. Goodrich, D. F. Morgan, N. D. Johnson.

Mallmann Iron Mining Company; Duluth; \$600,000; 60,000 shares; July 19, 1890. A. H. Viele, A. J. Trimble, F. L. Cowen.

Mankato Coal Oil and Mineral Company; Mankato; \$50,000; 1,000 shares; Jan. 14, 1887. P. Zimmerman, J. L. Ritter, G. E. Spatz, J. Hagen, P. A. Larson, W. P. Marston, C. E. Davis, E. Weaver, *et al.*

McNaughton Mining Company; Duluth; \$160,000; 1,600 shares; Oct. 16, 1886. J. F. Baars, Jr., J. D. Howard, W. O. Hughart, Jr., J. D. Ensign, R. McNaughton, W. J. Nelson.

Merrill Discovery Company; Minneapolis; \$15,000; 150 shares; Jan. 12, 1882. R. S. Innes, R. D. Russell, G. B. Kirkbride, T. G. Merrill, G. H. Keith, H. M. Goodhue, A. F. Elliot.

Merritt Mining and Milling Company; Minneapolis; \$150,000; 150,000 shares; July 1, 1885. R. B. Langdon, A. H. Linton, A. D. Coon, W. J. Hahn.

Mesaba Gold and Silver Mining Company; Rochester; \$70,000; 1,400 shares; Aug. 29, 1866. G. W. Baker, O. P. Stearns, S. Risker, O. P. Whitcomb, E. C. Jones, A. Gooding, C. H. Morrill, C. C. Jones, C. S. Younglove.

Mesaba Iron Company; Duluth; \$3,000,000; 100,000 shares; June 14, 1882. W. W. Spalding, H. P. Wieland, A. Ramsey, W. Harris, W. D. Williams, L. Stannard, J. Mercer.

Michigan Mining and Developing Company; Duluth; \$1,000,000; 40,000 shares; Nov. 5, 1887. Neil McInnis, E. W. Mæe, L. D. Cyr, W. J. Adams, J. Bale.

Minneapolis and Black Hills Mining Company; Minneapolis; \$1,500,000; 300,000 shares; Nov. 14, 1887. H. W. Carter, F. W. Reed, A. L. Loomis, E. D. N. Whitney, J. Hildreth, I. A. Olsen, M. O. Little.

Minneapolis and Gogebic Mining and Milling Company; Minneapolis; \$1,000,000; 200,000 shares; Nov. 21, 1888. I. J. Cox, W. H. Midde-
mist, A. D. Westby, D. F. Strobeck.

Minneapolis and Malaga Gold and Silver Mining Company; Minneapolis; \$1,250,000; April 12, 1888. R. J. Anderson, W. P. Douglas, J. M. Anderson.

Minneapolis Mica Mining Company; Minneapolis: \$250,000; 2,500 shares; July 16, 1884. P. B. Christian, R. H. Hawkinson, A. F. Scott, P. S. Janney, M. C. Chapman.

Minneapolis Mining and Milling Company; Minneapolis: \$30,000; 1,200 shares; Sept. 28, 1877. J. L. Pomeroy, C. B. Severance, S. P. Hawley, D. A. Tinkelpaugh.

Minneapolis Mining and Milling Company; Minneapolis: \$2,500,000; 100,000 shares; Oct. 17, 1884. M. A. Morey, V. Truesdell, A. A. Camp, R. F. Hurlburt, H. W. Armstrong.

Minneapolis Mining and Smelting Company; Minneapolis: \$2,500,000; 500,000 shares; Sept. 22, 1885. P. W. McAdow, J. R. Anderson, E. S. Case, J. V. Nye, G. D. Emery, E. J. Davenport, C. P. Chapman.

Minneapolis Mining and Stock Exchange; Minneapolis; Dec. 7, 1889. J. Hildreth, A. F. Olmsted, H. A. Turner, W. N. Viguers, J. R. Jones, C. J. Robertson, G. W. Cooley, R. L. Pratt.

Minneapolis Mining, Smelting and Refining Company; Minneapolis: \$50,000; Jan. 30, 1888. W. E. Steele, A. J. Blethen, A. J. Boardman.

Minnesota and Wisconsin Stone Company; Minneapolis: \$200,000; 4,000 shares; Feb. 5, 1886. E. H. Steele, C. C. Dunn, W. H. Hubbard, D. J. Spaulding, W. J. Thompson.

Minnesota Gold Mining Company; St. Paul: \$2,000,000; 100,000 shares; Nov. 22, 1885. H. M. Rice, H. M. Sibley, F. Steele, S. Miller, J. S. Prince, W. J. Cullen, R. Chute, S. H. Chute, W. W. Webb, J. E. Thomson. C. H. Oakes.

Minnesota Granite Company; St. Paul: \$15,000; 300 shares; Nov. 27, 1867. W. F. Davidson, W. A. Spencer, A. H. Wilder, H. L. Carver, H. B. Big: low.

Minnesota Iron Company; St. Paul: \$20,000,000; 200,000 shares; Nov. 14, 1882. C. Tower, E. Breitung, G. C. Stone, C. Tower, Jr., R. H. Lee.

Minnesota Lake Manitan Gold and Silver Mining Company; Benson: \$2,000,000; 1,000,000 shares; Aug. 14, 1884. T. Knudson, I. F. Young, G. Camden, T. J. Berjerson, H. Mercie, J. Ward, P. J. Johnson, *et al*.

Minnesota Mining Company; Monticello: \$100,000; 2,000 shares; July 20, 1886. H. L. Brazie, C. W. Boyd, J. N. Stacy, D. A. Melrose, W. M. Melrose, T. Melrose, A. Y. Eaton.

Minnesota Mining Company; Duluth: \$600,000; 6,000 shares; May 28, 1890. H. B. Moore, W. T. Bailey, W. B. Parsons, F. B. Kellogg, C. A. Severance.

Minnesota Natural Gas, Oil and Fuel Company; Albert Lea: \$1,500,000; 30,000 shares; Aug. 24, 1887. W. P. Sergeant, R. M. Todd, E. S. Prentice, D. F. Morgan, J. P. Hovland, C. C. Dwight, W. C. McAdam, J. H. Parker, T. V. Knatvold.

Minnesota Plumbago Company; Minneapolis: \$1,000,000; 40,000 shares; Feb. 10, 1888. M. J. Merrill, R. J. Baldwin, E. Russell, C. H. Tyler.

Minnesota Valley Gold and Silver Mining Company; Granite Falls: \$250,000; 10,000 shares; July 24, 1889. E. O'Connor, J. O'Connor, E. F. Rowe, T. A. Mellerroe, T. O'Connor.

Missouri Cannel Coal Mining Company; St. Paul: \$500,000; 5,000 shares; April 30, 1888. L. S. Chaffee, B. R. Cowen, H. C. Weakley, F. E. Weakley, J. W. Baker, W. W. Braden, G. F. Hamilton.

Mokoman Mining Company; Lake county: \$500,000; 10,000 shares; Sept. 9, 1864. E. Sales, J. P. Coulter, A. A. Parker, W. D. Williams.

Monarch Hydraulic Mining Company; St. Paul: \$1,000,000; 100,000 shares; Jan. 17, 1887. H. W. Carter, C. A. Gridler, J. M. Gilman, M. D. Munn.

Monitor Mining Company; Lake county; \$500,000; 10,000 shares; Sept. 9, 1864. A. Doolittle, J. Bentonshow, J. W. Crozer, A. A. Parker, W. D. Williams.

Monongahela County Agricultural and Mineral Society; Jan. 18, 1867. J. Tuttle, J. S. Whitla, C. E. Lien.

Montezuma Gold Mining Company; Minneapolis; \$1,000,000; 100,000 shares; June 22, 1886. D. Ryan, S. E. Dawson, H. Mattson, L. Jaeger.

Mo gan Mining and Reduction Company; Minneapolis; \$25,000; 250 shares; Aug. 12, 1887. J. B. Atwater, A. B. Jackson, G. C. Ripley, C. K. Davis, E. S. Goodrich, D. F. Morgan, N. D. Johnson.

Mountain Iron Comeany; Duluth; \$2,000,000; 20,000 shares; July 10, 1890. L. Merritt, J. T. Hale, R. H. Palmer.

Mountain King Mining Association; Winona; \$1,500,000; 60,000 shares; April 2, 1881. F. A. Johnston, E. M. Wilson, W. F. Phelps, C. H. Berry, C. J. Johnson, L. R. Brooks, E. G. Perkins, C. L. Coleman, S. Y. Hyde, C. L. Bonner, W. W. Cargill.

Mountain Range Iron Company; Duluth; \$50,000; 500 shares; May 31, 1889. L. Merritt, A. Merritt, C. C. Merritt, K. D. Chase, C. Chambers.

Mouse River Land Company; Minneapolis; \$60,000; 100 shares; Jan. 26, 1885. J. A. Bowman, C. E. Brown, C. P. Haseltine, W. H. Mitchell, M. H. Raymond.

Neptune Gold Mining Company; Minneapolis; \$750,000; 7,500 shares; Dec. 10, 1888. R. J. Anderson, W. P. Douglas, H. C. Hanford.

New Ulm Stone Company; New Ulm; \$25,000; 250 shares; Dec. 24, 1888. W. Boesch, G. G. Benz, A. Schell, J. Pfeuninger.

New Vienna Mining Company; \$500,000; 20,000 shares; Nov. 16, 1888; C. L. Coleman, H. J. O'Neill, F. A. Johnston, S. Y. Hyde, W. W. Cargill.

Nicollet Mining Company; Minneapolis; \$2,500,000; 250,000 shares; March 3, 1887. E. J. Davenport, G. D. Emery, J. V. Nye.

Norman Iron Company; Chicago, Ill.; \$50,000; 2,000 shares; April 13 1889. R. Spencer, A. C. Ely, J. W. Chandler.

North Dakota Coal Mining Company; St. Paul; \$200,000; 4,000 shares; Sept. 18, 1883. N. C. Deering, J. B. Cleland, W. L. Eaton, F. F. Coffin, F. H. True, W. A. Kirkham, J. T. Standring, L. Standring, T. W. Burdick, M. V. Richards.

Northeast Minnesota Mining Company; Minneapolis; \$2,500,000; 100,000 shares; April 27, 1887. A. C. Bruce, J. G. Emery Jr., J. Paulson.

Northern Gold Company; Minneapolis; \$40,000; 400 shares; April 22, 1889. W. A. DellPlain, P. K. K. Paulson, J. H. Cates.

North Shore Consolidated Silver Mining Company; St. Paul; \$500,000; 20,000 shares; Nov. 1, 1878. W. D. Washburn, A. H. Wilder, W. Lee, A. DeGraff, C. A. Morton, G. Culver, A. Wharton, O. P. Whitcomb, G. L. Moore, J. H. Baker, J. F. Magher.

North Shore Gold and Silver Mining Company; St. Paul; \$2,000,000; 200,000 shares; Feb. 11, 1888. O. N. Murdock, C. A. Stinson, H. S. G. Grasswell, J. M. Lynch, F. J. Bletcher, G. B. Shaw, G. H. Browne, A. F. Olmsted.

North Shore Mining Company; Duluth; \$100,000; 2,000 shares; Aug. 13, 1863. R. T. Paine, H. B. Paine, R. B. Carlton, E. S. Goodrich, G. L. Becker.

North Shore Mining Company; Detroit, Mich.; \$1,000,000; 40,000 shares; May 24, 1888. W. P. Spalding, H. F. Eberts, R. R. Paulson.

North Shore Silver and Copper Mining Company; Duluth; \$2,500,000; 100,000 shares; April 15, 1884. B. B. Spalding, J. McBeth, E. W. Wakelin, J. Ruttle, J. S. Daniels, J. S. Crawford, S. H. Seelye, W. Dunlap, W. B. Gahan, M. Paine, J. E. Knowlton, H. H. Hawkins.

North Star Gold and Silver Mining Company; Minneapolis; \$60,000; 1,200 shares; Feb. 20, 1866. J. M. Waldron, T. M. Linton, R. P. Russell, G. A. Brackett, P. Gibson.

North Star Iron Land Company; Duluth; \$100,000; 4,000 shares; March 14, 1887. L. Silverman, J. Frank, B. Moos, E. Hartmann, R. D. Mallet.

North Superior Iron Mining Company; Duluth; \$1,000,000; 40,000 shares; April 23, 1887. W. W. Spalding, H. M. Francis, F. W. McKinley.

Northwestern Coal Mining Company; Minneapolis; \$1,000,000; 40,000 shares; March 23, 1888. W. E. Jones, W. C. Jones, C. W. Jones, F. H. Remington.

Northwestern Gold and Silver Mining Company, of Minnesota; St. Paul; \$500,000; 10,000 shares; Jan. 5, 1865. C. E. Davis, J. W. Webb, J. H. Place, J. McGraves, T. Ranck, J. Condit.

Northwestern Mining Company; Minneapolis; \$10,000; 200 shares; Dec. 23, 1884. H. N. Farnam, Carrie H. Farnam, H. G. Cable.

Northwestern Mining Exchange; St. Paul; \$27,000; 270 shares; April 19, 1887. G. D. M. Sherman, H. S. Chase, M. W. Gasser, F. J. Bletcher, H. W. Wack, H. L. Bryant, M. M. Metcalf, H. L. Wheat, B. M. Bicksler.

Northwestern Natural Gas, Oil and Mining Company; St. Paul; \$500,000; 5,000 shares; March 17, 1887. F. J. Cleminger, W. G. Hunter, H. Brawley.

Oil, Gas and Water Well-Drilling Company; St. Paul; \$50,000; 500 shares; Feb. 28, 1890. H. Barton, D. N. Harris, J. C. Barton, S. A. Anderson, S. T. Conkling.

Old Veteran Mining Company; Minneapolis; \$1,000,000; 80,000 shares; Oct. 4, 1888. J. P. Nichols, R. R. Henderson, A. F. Nichols, G. H. Simpson, E. Nichols, C. W. Tracy, W. E. Hale.

Omega Iron Company; Minneapolis; \$800,000; 80,000 shares; May 27, 1887. D. D. Jones, F. V. Darrow, J. C. Jones, E. Gjertsen, I. L. Moore, B. H. Hellen, N. Goff, G. W. Williams.

Oneota Gold and Silver Mining Company; Duluth; \$1,000,000; 500,000 shares; April 2, 1884. A. E. Sears, J. Mallech, E. Lighthouse.

Ontario Silver Mining Company; St. Paul; \$2,000,000; 400,000 shares; June 1, 1887. E. H. C. Taylor, A. F. Russell, V. C. Gilman, A. K. Murray, W. J. Stevenson, T. Tyrer, R. M. Fulton.

Ontario Syndicate Mining Company; St. Paul; \$1,000,000; 100,000 shares; Dec. 30, 1887. J. H. Burwell, M. Auerbach, E. G. Rogers, T. Saulspaugh, H. P. Breed, R. B. Galusha, H. Sahlgaard.

Oriental Granite and Iron Company, Duluth; \$1,000,000; 40,000 shares; April 23, 1887. L. Silverman, J. Frank, B. Moos, E. Hartmann.

Philadelphia Gold Mining Company; Minneapolis; \$600,000; Nov. 19, 1888. C. A. Sparks, E. V. Douglas, R. Wetherill, Richard Wetherill, W. P. Douglas.

Pigeon River Mining Company; Duluth; \$250,000; 10,000 shares; May 17, 1883. C. J. Bower, W. Warner, W. M. Lenhart, G. F. Schutt, M. E. Chambers.

Pioneer Exploration and Mining Company; Duluth; \$1,000,000; 40,000 shares; July 23, 1888. J. T. Gregory, J. S. Ellis, W. H. Phipps, J. A. Humbird, J. H. James.

Pioneer Gold and Silver Mining Company, of Minnesota; St. Paul; \$500,000; 10,000 shares; Aug. 10, 1866. T. M. Newson, H. M. Lamborn, I. N. Steele, *et al.*

Pioneer Iron Mining Company; Duluth; \$1,000,000; 40,000 shares; July 16, 1886. E. J. Palmer, J. T. Gregory, J. S. Ellis, N. I. Willey, J. H. James.

Pipestone Quarrying Company; Pipestone; \$250,000; 5,000 shares; June 6, 1884. E. K. Wallbridge, L. H. Moore, H. E. Corbett.

Pleasant River Gold Mining Company; Minneapolis; \$100,000; 10,000 shares; Jan. 24, 1887. S. Leavitt, S. L. Bayliss, S. Schreiber.

Portland Stone Company; St. Paul; \$50,000; 500 shares; Nov. 14, 1885. P. Berkey, J. A. Berkey, W. P. Cockey, L. Washington.

Potter Mining, Smelting and Refining Company; Minneapolis; \$500,000; 20,000 shares; March 1, 1887. J. West, C. E. Baldwin, R. Bruce, R. L. Penney, T. G. Merrill, W. D. Pinkerton.

Premier Pent Company; St. Paul; \$300,000; 6,000 shares; Dec. 17, 1867. C. H. Oakes, C. D. Williams, M. R. Jeffers.

Queen Gold and Silver Mining and Milling Company; St. Paul; \$1,500,000; 300,000 shares; April 14, 1887. H. S. Sibley, C. G. Kimball, J. A. Boak, J. H. Hullsilk, A. H. Truax, J. Q. Haas, A. C. Ramsden.

Rainy Lake Mining and Improvement Company; Duluth; \$100,000; 100,000 shares; Oct. 23, 1890. L. S. Franklin, A. Thompson, J. H. Norby, C. W. Ericson, B. Fenstad, J. A. Rowneng, W. Ericson.

Rawdon Gold Mining Company; St. Paul; \$250,000; 2,500 shares; Aug. 30, 1886. E. C. Long, A. D. McLeod, G. Graham, E. A. Long, J. Graham.

Red Pipestone Quarrying Company; Pipestone; \$50,000; 500 shares; Oct. 24, 1889. J. M. Poorbaugh, T. A. Black, E. W. Davies.

Redwood Coal Company; St. Paul; \$10,500; 210 shares; Oct. 12, 1864. H. H. Sibley, J. S. Prince, F. Steele, C. H. Oakes, H. M. Rice.

Richmond Mining Company; Richmond; \$10,000; 400 shares; March 8, 1880. J. Simonitsch, J. Schneider, J. Berghoff, M. A. Busson.

Rio Grande Mining Association; Winona; \$500,000; 5,000 shares; June 1, 1882. R. A. Jones, C. C. Hughes, E. C. Stewart, J. F. Read, D. B. Burdette.

River Iron Mining Company; St. Paul; \$1,000,000; 40,000 shares; March 12, 1887. F. M. Ferris, J. D. Cameron, R. G. Baldwin, H. C. Masters, W. S. Reynolds, C. B. Walker, C. A. Greeley, *et al.*

Sage-Emery Mining Syndicate; Minneapolis; \$2,500,000; 100,000 shares; April 27, 1887. J. G. Emery, T. Emery, V. W. Bayless.

Sand Coulee Coal Company; St. Paul; \$250,000; 2,500 shares; July 27, 1888. W. P. Clough, M. D. Grover, E. Sawyer.

Sauk River Mining Company; Richmond; \$200,000; 1,000 shares; Sept. 25, 1871. H. P. Daendels, J. Eder, W. Erdman.

Sault Ste. Marie Quarrying and Mining Company; Minneapolis; \$50,000; 1,000 shares; April 3, 1889. A. M. Jordan, W. G. Tice, C. M. Jordan, T. W. Hammond.

Sharp Iron Mining and Smelting Company; Minneapolis; \$1,500,000; 60,000 shares; Sept. 28, 1887. L. M. Sharp, T. H. Monahan, E. H. Page, J. F. Forze, H. Byrnes, R. E. Trafton, F. Murdock.

Sheridan Iron Company; St. Louis county; \$1,000,000; 10,000 shares; Sept. 27, 1887. H. S. Pickands, W. L. Brown, J. H. Chandler.

Sentinel Gold Mining Company; Minneapolis; \$750,000; 75,000 shares; Dec. 22, 1884. N. H. Hemiup, A. P. Walrath, S. H. Baker, A. A. Camp, R. F. Hurlburt.

Silver and Copper Island Mining Company, of Minnesota; St. Paul; \$2,000,000; 1,000,000 shares; June 14, 1882. J. N. Stewart, C. G. Kimball, C. A. Heffelfinger, W. A. Kindred.

Silver Bell Mining Company; Rochester; \$200,000; 2,000 shares; July 26, 1881. G. W. VanDusen, R. A. Newton, C. H. Chadbourne, A. Gooding, H. T. Hannon, L. E. Cowdery, A. Harrington, S. E. Newton, C. VanCampen.

Silver City Mining Company; Duluth; \$1,000,000; 100,000 shares; Nov. 22, 1884. D. T. Adams, J. Evans, J. A. Stockbridge, J. M. Sharp, G. Anderson, A. P. Dodge, O. W. Fish, T. A. Bury, J. D. Howard. (Company dissolved by order of court).

Silver Lake Mining Company; Duluth; \$2,000,000; 200,000 shares; April 27, 1888. A. D. Cummings, H. R. Tinkham, J. H. Hillyer, E. Tinkham.

Silver Lead Mining Company; St. Paul; \$1,000,000; 200,000 shares; Feb. 23, 1889. O. A. Turner, E. B. Northrop, C. C. Mister. (Moved to Montana).

Silver Ore Mining Company; St. Paul; \$50,000; 5,000 shares; June 17, 1885. F. Wilde, C. Faber, A. Bärmann, M. Toltz, J. W. Gandsay, J. C. Simonet, *et al.*

Silver Star Mining Company; Stillwater; \$1,200,000; 48,000 shares; Oct. 12, 1887. R. S. Davis, E. W. McClure, J. W. Shupp, A. G. Triebel, *et al.*

Sixty-Three Twelve Iron Land Company; Duluth; \$1,000,000; 40,000 shares; Oct. 8, 1887. L. Silverman, J. Frank, B. Moos, E. Hartmann, R. D. Mallet.

Solid Gold and Silver Mining Company; Minneapolis; \$400,000; 40,000 shares; May 24, 1883. J. C. Phillips, C. E. Whelpley, C. E. Conant, N. H. Hemiup, I. A. Barnes, S. H. Wood, W. D. Haycock.

South Superior Gold and Silver Mining and Milling Company; Minneapolis; \$250,000; 250,000 shares; Aug. 19, 1890. S. Parker, E. E. Blinn, M. N. Price, J. L. Parker, A. D. Westby.

South Washburn Mining and Smelting Company; Minneapolis; \$1,250,000; 50,000 shares; Feb. 16, 1888. A. D. Westby, D. F. Strobeck, C. B. Holmes.

Standard Gold Mining and Milling Company; Minneapolis; \$2,000,000; 200,000 shares; Nov. 29, 1890. J. C. Stout, H. D. Stocker, R. T. Lang, G. L. Matchan, N. Galles, M. Thompson.

Stanton Mining Company; St. Paul; \$100,000; 10,000 shares; Dec. 1, 1886. C. M. Ramsey, H. C. Davis, W. S. Alexander, R. B. Galusha, A. F. Hughes.

S. Cloud Granite Quarrying and Manufacturing Company; St. Paul; \$100,000; 2,000 shares; Aug. 16, 1875. H. Rogers, W. M. Tileston, D. W. Wellman, W. D. Rogers, L. A. Evans.

Stillwater Mining Company; Minneapolis; \$800,000; 16,000 shares; Sept. 22, 1885. J. V. Nye, P. McA Dow, J. Anderson, E. S. Case, G. D. Emery, E. J. Davenport, C. P. Chapman.

Stillwater Mining Company; Minneapolis; \$1,000,000; 400,000 shares April 29, 1887. P. Potts, L. P. Richardson, G. H. Atwood, A. M. Dodd, E. A. Phinney, W. A. Chambers, O. A. Watier.

Stillwater Natural Gas and Oil Company; \$50,000; 10,000 shares; Dec. 1, 1887. E. W. Durant, J. McCusick, D. Tozer, A. K. Doe, J. C. Nethaway.

St. Louis Iron Mining Company; Duluth; \$1,000,000; 100,000 shares; March 28, 1887. R. H. Lee, I. P. Beck, A. J. Whiteman, A. H. Viele, W. B. Dixon, C. B. Woodruff.

Stone Iron Company; Duluth; \$600,000; 60,000 shares; April 26, 1890. G. C. Stone, J. Sellwood, J. B. Geggie.

Stonewall Mining Company; St. Paul; \$2,500,000; 100,000 shares; Feb. 6, 1884. D. Schutte, J. M. Pottgiesser, S. Dearing, R. B. Galusha, W. S. Alexander, J. Hill, W. H. Fisher.

St. Paul and Black Hills Gold Mining Company; St. Paul; \$50,000; 2,000 shares; March 22, 1877; A. H. Merrick, C. D. Williams, W. S. Alexander, T. Brennan, C. Messer, T. M. Newson, C. R. Groff, N. Meyrick.

St. Paul and Dunn County Mining Corporation; St. Paul; \$500,000; 20,000 shares; June 22, 1887. E. S. Norton, P. J. Schmitz, T. C. Hand, J. M. Bohrer, A. Boldigheimer.

St. Paul and Pacific Coal and Iron Company; St. Paul; \$100,000; 1,000 shares; Aug. 30, 1883. H. Pratt, L. C. Hanna, A. Pugh.

St. Paul Clay and Mining Company; St. Paul; \$10,000; 200 shares; Nov. 19, 1888. J. C. Stickney, R. C. Wight, W. M. Jones.

Sullivan Iron Company; Duluth; \$50,000; May 19, 1890. J. T. Hale, J. M. Smith, H. W. Coffin, J. T. Snively, C. P. Craig, S. F. Wadhams.

Summit Mining and Smelting Company; St. Paul; \$2,500,000; 250,000 shares; Feb. 27, 1888. E. H. Smith, A. F. Stewart, E. S. Case, H. A. Thompson, H. S. Potts.

Swan Iron Mining Company; Minneapolis; \$1,000,000; 40,000 shares; Jan. 29, 1887. E. J. Swan, G. W. Payne, E. A. Sumner.

Swart Gold and Silver Mining Company; Wabasha; \$500,000 20,000 shares; Dec. 27, 1887. G. H. Swart, C. Jellison, W. M. McDonald.

Taylor's Falls Copper Mining Company; Taylor's Falls; \$200,000; 20,000 shares; Dec. 6, 1874. W. H. C. Folsom, G. W. Seymour, T. W. Folsom, J. L. Taylor, D. A. Caneday, C. Hauser, J. Schottmuller.

Temperance River Silver and Copper Mining Company; Duluth; Feb. 9, 1884. S. H. Seelye, J. E. Knowlton, J. A. Mannheim, J. F. Baars, Jr., F. W. Paine, M. Thomas, J. C. VanNorman.

Thunder Bay Gold and Silver Mining Company; St. Paul; \$2,000,000; 200,000 shares; April 4, 1889. R. L. Wharton, C. A. Stinson, F. M. Cady, R. F. Marvin, J. J. Dougher, C. B. Marvin, J. R. Mansfield, T. J. Willbeck, A. F. Olmsted, *et al.*

Union Gold and Silver Mining Company, of Minnesota; St. Paul; \$500,000; 10,000 shares. Aug 10, 1866. T. M. Newson, G. P. Harris, *et al.*

Union Iron Company; Duluth; \$400,000; 40,000 shares; Jan. 30, 1889; J. H. James, J. Megins, W. C. Sherwood, A. J. Lonstorf, J. Bale.

Union Iron Mining Company; Duluth; \$1,000,000; April 6, 1887. J. Paulson, W. W. Spalding, J. D. Stryker, F. W. McKinney, H. M. Francis.

Union Mining, Smelting and Refining Company; Duluth; \$1,000,000; 10,000 shares; Jan. 19, 1887. O. P. Stearns, C. H. Graves, C. Markell, D. G. Cash, J. D. Ensigen.

Union Quartz Mining and Milling Company; Winona; \$300,000; 3,000 shares; Dec. 19, 1881. C. L. Colman, A. De Graff, F. A. Johnston, A. D. Ellsworth; H. J. O'Neill.

U. S. Mining and Milling Company; Minneapolis; \$250,000; 250,000 shares; Dec. 4, 1890. A. B. Trombly, G. W. Robinson, H. Shear, C. J. Woodward, C. E. Moore, G. H. Eastman, A. F. Olmsted.

Vermilion and Grand Marais Iron Company; Duluth; \$5,000,000; 500,000 shares; Dec. 11, 1888. H. W. Sibley, D. S. Fox, I. Bearinger, H. M. Loud, G. T. Walker, C. S. Brown, W. McKinley, F. W. Paine, H. Williston, *et al.*

Vermilion Falls Gold Mining Company; St. Paul; \$300,000; 6,000 shares; Nov. 8, 1865. O. E. Dodge, E. A. Dodge, C. D. Gilfillan, J. Gilfillan, C. D. Williams.

Vermilion Iron and Land Company, of Duluth; Duluth; \$1,000,000; 100,000 shares; March 26, 1883. J. W. Achom, A. H. Holgate, G. T. Johns, W. H. Smallwood.

Vermilion Iron Mining and Improvement Company, of St. Paul; St. Paul; \$2,500,000; 100,000 shares; Aug. 12, 1887. C. L. Taylor, O. E. Millis, P. D. Youngman, W. L. Lamb.

Vermilion Land and Iron Syndicate; Duluth; \$3,000,000; 750,000 shares; March 23, 1887. W. W. Spalding, H. K. Bell, F. W. McKinney, H. M. Francis, J. Paulson, R. J. Wemyss, C. H. Arthur.

Vermilion Mining Company; Duluth; \$1,000,000; 40,000 shares; Jan. 17, 1887. J. R. Myers, H. H. Myers, B. F. Myers.

Vermilion Range Iron Company; Duluth; \$1,000,000; 100,000 shares; Nov. 5, 1887. C. E. Shannon, J. M. McKinley, J. A. Willard, G. F. Piper, W. Foulke.

Vermilion Range Iron Company; Duluth; \$50,000; 500 shares; May 31, 1889. L. Merritt, A. Merritt, C. C. Merritt, R. D. Chase, C. Chambers.

Vermilion Range Lumber and Iron Company; Minneapolis; \$100,000; 10,000 shares; Jan. 22, 1890. L. Howland, R. W. Gilkey, C. B. Lampson, W. J. Monahan, F. C. Laird.

Vermilion Range Mining Syndicate; Minneapolis; \$2,500,000; 100,000 shares; April 27, 1887. J. G. Emery, T. Emery, J. Paulson.

Vienna Consolidated Mining Company; Winona; \$675,000; 27,000 shares; March 5, 1881. E. M. Wilson, F. A. Johnston, C. J. Johnston, C. H. Berry, W. F. Phelps, O. B. Gould, C. A. Morey, C. H. Mills, H. C. Shepherd, E. F. Curtis, R. T. Doud, *et al.*

Vienna Mining Company; Winona; \$15,000,000; 150,000 shares; March 23, 1882. C. L. Coleman, A. De Graff, H. J. O'Neill, A. D. Ellsworth, C. H. Berry, B. H. Langley, C. L. Bonner, F. A. Johnston, L. Y. Hyde.

Wabasha Black Hoof Mining Company; Wabasha; \$200,000; 4,000 shares; June 29, 1867. F. Klinge, M. E. Wetherbee, J. E. Morrison, A. W. Ditmars, J. Crowley, D. Schutte, S. Lyon.

Wabasha Mining Company; Wabasha; \$500,000; 20,000 shares; Sept. 5, 1887. J. H. Mullen, C. Jellison, G. H. Swart.

Washburn Mining and Milling Company; Minneapolis; \$1,000,000; 200,000 shares; July 26, 1888. W. H. Middlemist, A. D. Westby, D. F. Strobeck.

Wasioja Stone Company; Dodge Centre; \$60,000; 1,200 shares; Feb. 21, 1889. J. A. Green, W. B. Parsons, W. E. Richardson, F. C. A. Day.

War Eagle Gold and Silver Mining and Milling Company; St. Paul; \$2,500,000; 250,000 shares; Feb. 21, 1883. J. M. McCafferty, E. A. Fitzgerald, M. Treacy, P. Durack, E. Kelley, J. Norton, *et al.*

Watab Gold and Silver Mining Company; St. Paul; \$500,000; 10,000 shares; Sept. 25, 1867. C. D. Montreville, T. M. Newson, J. Gilman.

Waterloo Iron Mining and Smelting Company; Minneapolis; \$1,500,000; 60,000 shares; March 28, 1888. J. Ruhe, L. Matthews, E. Munger;

Watertown and La Crosse Gold and Silver Mining Company; Minneapolis; \$500,000; 10,000 shares; June 30, 1866. I. I. Lewis, S. M. Tarvin, L. Brandt, W. B. Ellis, H. J. McKee, E. Hamlin, D. M. Lusk, C. V. Kingsley, M. M. Ryan, W. F. Robinson.

Western Transportation and Mining Company; \$100,000; 1,000 shares; May 1, 1871. (Changed into Lake Superior and Puget Sound Company). A. Coburn, R. Coburn, R. D. Rice.

West Superior Iron and Steel Company; St. Paul; \$2,500,000; 25,000 shares; May 8, 1883. R. L. Belknap, F. H. Weeks, R. J. Wemyss, J. F. Oakes, H. W. DeForest, J. Roosevelt, J. B. Williams, J. H. Ames.

Whitefish Lake Mining and Manufacturing Company; Duluth; \$1,500,000; 150,000 shares; Dec. 30, 1884. J. H. Caldwell, T. F. McGowan, A. Fraser, E. Jordan, N. Thomas, H. C. Kendall, C. J. Bower, G. Bruette.

White Iron Lake Iron and Water Power Company; Duluth; \$1,000,000; 100,000 shares; Sept. 20, 1888. F. W. Eaton, R. Fagan, H. W. Bell, E. Brown, H. M. Loud, D. L. Walker, D. S. Fox, C. S. Brown.

White Spar Mica Mining Company; Minneapolis; \$2,500,000; 100,000 shares; Dec. 20, 1888. E. A. Scales, R. B. Vining, C. B. Dickens, A. F. Olmsted, C. B. Lawton.

White Spar Mica Company; Minneapolis; \$25,000; 1,000 shares; Oct. 9, 1884. S. Chapman, E. S. Kelly, D. Olmsted, J. E. Miner, C. G. Rogers.

Wilmina Silver Mining and Smelting Company; St. Paul; \$50,000; 2,000 shares; Oct. 27, 1877. A. Lewis, W. H. Schreffler, F. Moorhead, W. O. Rogers, S. E. Bright.

Winnipeg and Northwest Petroleum Company; Minneapolis; \$1,000,000; 100,000 shares; Oct. 12, 1883. C. T. Gregory, F. C. Butterfield, E. R. Kent.

Winona County Mining Company; Dresbach; \$100,000; 4,000 shares; April 17, 1880. G. B. Dresbach, E. S. Burns, G. Widmoyer, G. Johnson, W. H. Sherwood, L. Blumentritt, F. Rodolf, G. Pindell, J. J. Gunther, J. M. Turner.

Wisconsin Central Mining Company; Stillwater; \$1,500,000; 60,000 shares; July 7, 1887. M. M. Colliner, P. Potts, S. P. Richardson, L. A. Gottschall, L. Albenberg, M. Albenberg, F. C. Chartrand.

Wolverine Iron Mining Company, of St. Paul; St. Paul; \$1,000,000; 40,000 shares; Sept. 6, 1887. J. N. Smith, B. F. Ferris, G. H. Browne, H. P. Haskell, E. F. Maybee, J. H. Chamberlin, C. H. Morse, W. A. Barr, *et al.*

Wurst Mining and Manufacturing Company; St. Paul; \$100,000; 2,000 shares; Aug. 27, 1885. J. H. Kneass, T. W. Teasdale, R. W. Cavanaugh, W. H. Farnham, W. W. Sly, M. Wurst.

Zenith Iron Mining Company; Duluth; \$1,000,000; 40,000 shares; March 28, 1887. E. Ellis, G. C. Greenwood, J. T. Gregory, R. D. Mallet, J. H. James.

Zumbro Lead Mining Company; Wabasha; \$60,000; 2,400 shares; March 15, 1868. F. Klinge, A. C. Remondino, W. Wetherbee, J. Crowley, J. E. Morrison, O. Monette, E. H. Davis.

STA LANDS LEASED UNDER THE ACT OF THE LEGISLATURE OF 1889.*

To Whom Leased.	Parts of Sections.	Section.	Township	Range.	Date.
James B. Giggie.....	SE $\frac{1}{4}$ of SE $\frac{1}{4}$	20	59	14	Aug. 28, 1889
W. B. Parsons.....	N $\frac{1}{2}$ SW $\frac{1}{4}$ and W $\frac{1}{2}$ NW $\frac{1}{4}$..	16	62	14	Mch. 1, 1890
W. B. Parsons.....	SE $\frac{1}{4}$	36	63	13	Mch. 1, 1890
C. A. Severance.....	S $\frac{1}{2}$ of S $\frac{1}{2}$	16	62	14	Mch. 1, 1890
C. A. Severance.....	N $\frac{1}{2}$ of SE $\frac{1}{4}$ and S $\frac{1}{2}$ of NE $\frac{1}{4}$	16	62	14	Mch. 1, 1890
C. W. G. Withee.....	SW $\frac{1}{4}$	36	63	13	Mch. 1, 1890
C. W. G. Withee.....	NE $\frac{1}{4}$	36	63	13	Mch. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	58	19	Mch. 8, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	58	19	Mch. 8, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	58	19	Mch. 8, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	58	19	Mch. 8, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	58	21	Mch. 8, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	58	21	Mch. 8, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	58	21	Mch. 8, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	58	21	Mch. 8, 1890
George L. Robbins.....	NE $\frac{1}{4}$ of SE $\frac{1}{4}$ and S $\frac{1}{2}$ of SE $\frac{1}{4}$	15	59	14	Mch. 8, 1890
George L. Robbins.....	S $\frac{1}{2}$ of SW $\frac{1}{4}$	15	59	14	Mch. 8, 1890
George L. Robbins.....	S $\frac{1}{2}$ of SE $\frac{1}{4}$	16	59	14	Mch. 8, 1890
George L. Robbins.....	NW $\frac{1}{4}$	13	59	14	Mch. 8, 1890
George L. Robbins.....	NE $\frac{1}{4}$	14	59	14	Mch. 8, 1890
George L. Robbins.....	NE $\frac{1}{4}$ of NW $\frac{1}{4}$ and S $\frac{1}{2}$ of NW $\frac{1}{4}$ and NW $\frac{1}{4}$ SW $\frac{1}{4}$..	23	59	14	Mch. 13, 1890
George L. Robbins.....	NE $\frac{1}{4}$	23	59	14	Mch. 13, 1890
George L. Robbins.....	E $\frac{1}{2}$ SW $\frac{1}{4}$ and SW $\frac{1}{4}$ of SW $\frac{1}{4}$	23	59	14	Mch. 13, 1890
Fannie O. Griffin and Anna P. Warner.....	E $\frac{1}{2}$ SE $\frac{1}{4}$ and SW $\frac{1}{4}$ of SE $\frac{1}{4}$ and SE $\frac{1}{4}$ of SW $\frac{1}{4}$	16	56	24	Mch. 13, 1890
Geo. L. Robbins.....	NW $\frac{1}{4}$ of NW $\frac{1}{4}$	26	59	14	Mch. 13, 1890
R. H. L. Jewett.....	E $\frac{1}{2}$ NE $\frac{1}{4}$ and NE $\frac{1}{4}$ of SE $\frac{1}{4}$	22	59	14	Mch. 13, 1890
R. H. L. Jewett.....	SW $\frac{1}{4}$ of NW $\frac{1}{4}$ and NW $\frac{1}{4}$ of SW $\frac{1}{4}$	14	59	14	Mch. 13, 1890
R. H. L. Jewett.....	SE $\frac{1}{4}$ of NE $\frac{1}{4}$	15	59	14	Mch. 13, 1890
Fred M. Washburn....	W $\frac{1}{2}$	36	59	17	Mch. 15, 1890
Fred M. Washburn....	W $\frac{1}{2}$ of E $\frac{1}{2}$	36	59	17	Mch. 15, 1890
Wm. A. McGonagh....	SE $\frac{1}{4}$	36	60	14	Mch. 17, 1890
E. V. Mundy.....	NW $\frac{1}{4}$	36	64	10	Mch. 17, 1890
John Paulson.....	SE $\frac{1}{4}$	36	65	1E	Mch. 17, 1890
John Paulson.....	S $\frac{1}{2}$	36	64	11	Mch. 17, 1890
A. T. Naff.....	NE $\frac{1}{4}$	36	63	12	Mch. 18, 1890
Andrew Myles.....	SW $\frac{1}{4}$	36	63	15	Mch. 18, 1890
Andrew Myles.....	SE $\frac{1}{4}$	36	63	15	Mch. 18, 1890
W. T. Bailey.....	NE $\frac{1}{4}$	36	64	10	Mch. 18, 1890
W. T. Bailey.....	SE $\frac{1}{4}$	36	64	10	Mch. 18, 1890
A. H. Earle.....	Lots 2, 3 and N $\frac{1}{2}$ of SE $\frac{1}{4}$	36	65	2E	Mch. 18, 1890
R. C. Judson.....	NW $\frac{1}{4}$	16	60	20	Mch. 18, 1890
R. C. Judson.....	SW $\frac{1}{4}$	16	60	20	Mch. 18, 1890
John J. Wheeler.....	Lots 1, 2, 4, SW of NW $\frac{1}{4}$	36	65	5	Mch. 20, 1890
Leonidas Merritt.....	Lots 4, 5, 6, 7.....	36	63	10	Mch. 20, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ SW $\frac{1}{4}$ and NE $\frac{1}{4}$ SE $\frac{1}{4}$ and S $\frac{1}{2}$ SE $\frac{1}{4}$	36	63	12	Mch. 20, 1890
John A. Davis.....	E $\frac{1}{2}$ NE $\frac{1}{4}$ and E $\frac{1}{2}$ of SE $\frac{1}{4}$..	36	59	17	Mch. 20, 1890
John A. Davis.....	E $\frac{1}{2}$ NW $\frac{1}{4}$ and E $\frac{1}{2}$ of SW $\frac{1}{4}$	36	59	17	Mch. 20, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	58	18	Mch. 20, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	58	18	Mch. 20, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	58	18	Mch. 20, 1890

*For a summary statement of this law see page 357.

To Whom Leased.	Parts of Sections.	Section.	Township	Range.	Date.
Leonidas Merritt.....	SE $\frac{1}{4}$	16	58	18	Mch.20,1890
Leonidas Merritt.....	NE $\frac{1}{4}$ SW $\frac{1}{4}$ and N $\frac{1}{4}$ of SE $\frac{1}{4}$ and SE $\frac{1}{4}$ of SE $\frac{1}{4}$	61	61	14	Mch.20,1890
Stephen L. Selder.....	Lots 4, 5 and S $\frac{1}{2}$ NW $\frac{1}{4}$...	36	65	2E	Mch.21,1890
Stephen L. Selder.....	Lot 1 and NW $\frac{1}{4}$ NE $\frac{1}{4}$ and E $\frac{1}{2}$ NE $\frac{1}{4}$	36	65	1E	Mch.21,1890
John M. Millar.....	NE $\frac{1}{4}$	16	64	6W	Mch.21,1890
John M. Millar.....	NW $\frac{1}{4}$	16	64	6W	Mch.21,1890
R. N. Marble.....	N $\frac{1}{2}$ NW $\frac{1}{4}$	36	63	12	Mch.21,1890
R. N. Marble.....	N $\frac{1}{2}$ NE $\frac{1}{4}$	16	62	13	Mch.21,1890
Belle L. Marble.....	E $\frac{1}{2}$ SW $\frac{1}{4}$	16	62	13	Mch.21,1890
W. H. Estep.....	Lots 2, 3 and NW $\frac{1}{4}$ of NW $\frac{1}{4}$	36	65	1E	Mch.21,1890
Morris Thomas.....	N $\frac{1}{2}$ of S $\frac{1}{2}$	16	63	10	Mch.21,1890
Morris Thomas.....	S $\frac{1}{2}$ of N $\frac{1}{2}$	16	63	10	Mch.21,1890
William H. Phipps....	NW $\frac{1}{4}$ of NW $\frac{1}{4}$	36	63	13	Mch.22,1890
Emil Hartmann.....	NE $\frac{1}{4}$	36	59	19	Mch.25,1890
Emil Hartmann.....	NW $\frac{1}{4}$	36	59	19	Mch.25,1890
Emil Hartmann.....	SW $\frac{1}{4}$	36	59	19	Mch.25,1890
Emil Hartmann.....	SE $\frac{1}{4}$	36	59	19	Mch.25,1890
Emil Hartmann.....	NE $\frac{1}{4}$	36	59	18	Mch.25,1890
Emil Hartmann.....	NW $\frac{1}{4}$	36	59	18	Mch.25,1890
Emil Hartmann.....	SW $\frac{1}{4}$	36	59	18	Mch.25,1890
Emil Hartmann.....	SE $\frac{1}{4}$	36	59	18	Mch.25,1890
Robert Loudon.....	E $\frac{1}{2}$ SW $\frac{1}{4}$ and NW $\frac{1}{4}$ of SW $\frac{1}{4}$	22	59	14	Mch.28,1890
Robert Loudon.....	S $\frac{1}{2}$ of NW $\frac{1}{4}$	22	59	14	Mch.28,1890
Robert Loudon.....	SE $\frac{1}{4}$ of NE $\frac{1}{4}$	21	59	14	Mch.28,1890
John R. Howes.....	N $\frac{1}{2}$ of NE $\frac{1}{4}$ and E $\frac{1}{2}$ of NW $\frac{1}{4}$	16	62	14	Mch.28,1890
D. J. Sinclair.....	S $\frac{1}{2}$ of NE $\frac{1}{4}$ and N $\frac{1}{2}$ of SE $\frac{1}{4}$	16	62	13	Mch.28,1890
A. H. Truax.....	SE $\frac{1}{4}$	36	64	8	Mch.30,1890
Leonidas Merritt.....	Lots 2, 3, 4 and SW $\frac{1}{4}$ of NW $\frac{1}{4}$	2	57	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ of NW $\frac{1}{4}$	2	57	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ of SW $\frac{1}{4}$	2	57	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ of SE $\frac{1}{4}$	10	57	22	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	57	22	Aprl. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	57	22	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	57	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	57	22	Aprl. 1, 1890
Leonidas Merritt.....	S $\frac{1}{2}$ of S $\frac{1}{2}$	18	57	22	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	58	22	Aprl. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	58	22	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	58	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	58	22	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ NW $\frac{1}{4}$, N $\frac{1}{2}$ SW $\frac{1}{4}$ and SW $\frac{1}{4}$ of SW $\frac{1}{4}$	16	60	23	Mch.29,1890
Leonidas Merritt.....	Lots 1, 2, 3 and NE $\frac{1}{4}$ of SE $\frac{1}{4}$	16	60	23	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	60	23	Mch.29,1890
Leonidas Merritt.....	S $\frac{1}{2}$ of S $\frac{1}{2}$	16	57	23	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	57	23	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	57	23	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$ of SW $\frac{1}{4}$	16	56	24	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	60	25	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	60	25	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	60	25	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	60	25	Mch.29,1890

To Whom Leased.	Parts of Sections.	Section.	Townsh'p	Range.	Date.
Leonidas Merritt.....	NE $\frac{1}{4}$	16	60	25	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	60	25	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	60	25	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	60	25	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	55	25	Aprl. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	55	25	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	55	25	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	55	25	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$ of SW $\frac{1}{4}$	14	54	25	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$ of SE $\frac{1}{4}$	15	54	25	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$ of NE $\frac{1}{4}$	22	54	25	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	59	26	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	59	26	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	59	26	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	59	26	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	60	26	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	60	26	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	60	26	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	60	26	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	55	26	Aprl. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	55	26	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	55	26	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	55	26	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	24	59	27	Mch.29,1890
Leonidas Merritt.....	N $\frac{1}{2}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ and NE $\frac{1}{4}$ SE $\frac{1}{4}$	26	59	27	Mch.29,1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	59	27	Aprl. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	59	27	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	59	27	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	59	27	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	146	25	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	146	25	Mch.29,1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	146	25	Mch.29,1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	146	25	Mch.29,1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	56	26	Aprl. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	56	26	Aprl. 1, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	56	26	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	56	26	Aprl. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	147	25	Mar.29, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	147	25	Mar.29, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	147	25	Mar.29, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	147	25	Mar.29, 1890
Leonidas Merritt.....	Lot 3 and 4 and SW $\frac{1}{4}$ of NE $\frac{1}{4}$	6	55	25	Apr. 1, 1890
Leonidas Merritt.....	W $\frac{1}{2}$ of SW $\frac{1}{4}$	10	55	25	Apr. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$ NW $\frac{1}{4}$ and NW $\frac{1}{4}$ SW $\frac{1}{4}$	9	54	25	Apr. 1, 1890
Leonidas Merritt.....	N $\frac{1}{2}$ of SE $\frac{1}{4}$	8	54	25	Apr. 1, 1890
Leonidas Merritt.....	Lots 4 and 5.....	16	54	25	Apr. 1, 1890
Leonidas Merritt.....	E $\frac{1}{2}$ of SW $\frac{1}{4}$	9	54	25	Apr. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$ of SE $\frac{1}{4}$	14	57	23	Apr. 1, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$ of NE $\frac{1}{4}$	24	57	23	Apr. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$ of NE $\frac{1}{4}$	28	57	23	Apr. 1, 1890
Leonidas Merritt.....	W $\frac{1}{2}$ of NW $\frac{1}{4}$	28	57	23	Apr. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$ of NE $\frac{1}{4}$	22	57	23	Apr. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$ of NE $\frac{1}{4}$	2	56	24	Apr. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	59	26	Apr. 1, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	30	59	26	Apr. 1, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	24	59	27	Apr. 1, 1890

To Whom Leased.	Parts of Sections.	Section.	Townsh'p	Range.	Date.
Leonidas Merritt.....	SE $\frac{1}{4}$	36	60	23	Apr. 1, 1890
Charles F. Howe.....	W $\frac{1}{2}$ SW $\frac{1}{4}$, NE $\frac{1}{4}$ SW $\frac{1}{4}$ and Lot 2.....	36	64	10	Apr. 4, 1890
Alexander Frazer.....	SW $\frac{1}{4}$	36	64	8	Apr. 5, 1890
Thomas B. Dickens...	Lots 1, 2 and 3.....	16	63	11	Apr. 5, 1890
Leonidas Merritt.....	Lots 3, 7, 8 and SW $\frac{1}{4}$ of NE $\frac{1}{4}$	36	65	5	May 15, 1890
Leonidas Merritt.....	Lots 9, 10 and N $\frac{1}{2}$ NE $\frac{1}{4}$...	36	65	5	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	62	14	May 15, 1890
Leonidas Merritt.....	S $\frac{1}{2}$ NW $\frac{1}{4}$ and S $\frac{1}{2}$ NE $\frac{1}{4}$	36	63	12	May 15, 1890
Leonidas Merritt.....	N $\frac{1}{2}$ SW $\frac{1}{4}$, SW $\frac{1}{4}$ SW $\frac{1}{4}$ and NW $\frac{1}{4}$ SE $\frac{1}{4}$	36	63	12	May 15, 1890
Leonidas Merritt.....	Lot 5.....	16	63	10	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	63	1E	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	63	1E	May 15, 1890
Leonidas Merritt.....	Lots 1, 2 and 5.....	16	64	2w	May 15, 1890
Leonidas Merritt.....	N $\frac{1}{2}$ NE $\frac{1}{4}$, SW $\frac{1}{4}$ NE $\frac{1}{4}$ and lot 3.....	16	64	2w	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$..	16	60	12	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	60	12	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	60	12	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	60	12	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	62	15	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	61	14	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	58	17	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	58	17	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	58	17	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	16	58	17	May 15, 1890
Leonidas Merritt.....	N $\frac{1}{2}$ NE $\frac{1}{4}$, SW $\frac{1}{4}$ NE $\frac{1}{4}$, SE $\frac{1}{4}$ NW $\frac{1}{4}$	16	59	18	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	16	59	18	May 15, 1890
Leonidas Merritt.....	W $\frac{1}{2}$ SE $\frac{1}{4}$, NE $\frac{1}{4}$ SE $\frac{1}{4}$, SE $\frac{1}{4}$ NE $\frac{1}{4}$	16	59	18	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	58	19	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	58	19	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	58	19	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	58	19	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	60	17	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	60	17	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	60	17	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	60	17	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	60	18	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	60	18	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	60	18	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	60	18	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	16	60	18	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	16	60	18	May 15, 1890
Leonidas Merritt.....	Lots 3 and 4 and W $\frac{1}{2}$ of SW $\frac{1}{4}$	16	60	18	May 15, 1890
Leonidas Merritt.....	Lots 1, 2 and 6.....	16	60	18	May 15, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$	36	58	18	May 15, 1890
Leonidas Merritt.....	NW $\frac{1}{4}$	36	58	18	May 15, 1890
Leonidas Merritt.....	SW $\frac{1}{4}$	36	58	18	May 15, 1890
Leonidas Merritt.....	SE $\frac{1}{4}$	36	58	18	May 15, 1890
Leonidas Merritt.....	S $\frac{1}{2}$ of N $\frac{1}{2}$	16	64	4w	May 15, 1890
Leonidas Merritt.....	N $\frac{1}{2}$ of S $\frac{1}{2}$	16	64	4w	May 15, 1890
Geo. L. Robbins.....	W $\frac{1}{2}$ NW $\frac{1}{4}$, W $\frac{1}{2}$ SW $\frac{1}{4}$	36	63	10	May 15, 1890
Cassius C. Merritt.....	NE $\frac{1}{4}$	16	59	13	Dec. 15, 1890

To Whom Leased.	Parts of Sections.	Section.	Township	Range.	Date.
Cassius C. Merritt.....	SE $\frac{1}{4}$	16	59	13	Dec. 15, 1890
Andrew R. Merritt.....	NW $\frac{1}{4}$	16	59	13	Dec. 15, 1890
Andrew R. Merritt.....	SW $\frac{1}{4}$	16	59	13	Dec. 15, 1890
Lewis J. Merritt.....	NE $\frac{1}{4}$	36	60	13	Dec. 15, 1890
Lewis J. Merritt.....	SE $\frac{1}{4}$	36	60	13	Dec. 15, 1890
L. F. Merritt.....	NW $\frac{1}{4}$	36	60	13	Dec. 15, 1890
L. F. Merritt.....	SW $\frac{1}{4}$	36	60	13	Dec. 15, 1890
J. W. Stone.....	SE $\frac{1}{4}$ of NW $\frac{1}{4}$	15	59	14	May 17, 1890
J. W. Stone.....	N $\frac{1}{2}$ of NE $\frac{1}{4}$	27	59	14	May 17, 1890
Severt M. Severtson.....	N $\frac{1}{2}$ NW $\frac{1}{4}$, Lots 1 and 2...	16	63	10	May 20, 1890
Randolph L. Frazer.....	NW $\frac{1}{4}$ SE $\frac{1}{4}$ and Lot 6....	16	63	10	May 20, 1890
Randolph L. Frazer.....	S $\frac{1}{2}$ SW $\frac{1}{4}$	16	63	10	May 20, 1890
Thomas Griffen.....	SE $\frac{1}{4}$ NW $\frac{1}{4}$	14	59	14	Jun. 14, 1890
Thomas Griffen.....	SE $\frac{1}{4}$	14	59	14	Jun. 26, 1890
H. Mayhew.....	NW $\frac{1}{4}$	36	61	2w	Jun. 26, 1890
E. W. Wakelin.....	SW $\frac{1}{4}$	36	61	2w	Jun. 26, 1890
Leonidas Merritt.....	NE $\frac{1}{4}$ of NE $\frac{1}{4}$	6	58	17	July 25, 1890
H. Mattson and H. Eus- trom.....	NE NE, S $\frac{1}{2}$ NE $\frac{1}{4}$, NW $\frac{1}{4}$ of SE $\frac{1}{4}$	16	56	24	Sep. 1, 1890
L. T. Watson.....	NW $\frac{1}{4}$ NE $\frac{1}{4}$, N $\frac{1}{2}$ NW, SW $\frac{1}{4}$ NW $\frac{1}{4}$	16	56	24	Sep. 1, 1890
John Watson.....	N $\frac{1}{2}$ SW $\frac{1}{4}$ and SE $\frac{1}{4}$ NW $\frac{1}{4}$..	16	56	24	Sep. 1, 1890
Nicholas Probeck.....	Lots 1, 2, 3 and 7.....	16	65	2w	Sep. 11, 1890
H. Mayhew.....	Lots 4, 5 and 6 and SW $\frac{1}{4}$ SW $\frac{1}{4}$	16	65	2w	Sep. 11, 1890
M. L. Kenyon.....	W $\frac{1}{2}$ of NW $\frac{1}{4}$	28	59	14	Oct. 1, 1890
D. J. Tew and H. W. Eldrud.....	W $\frac{1}{2}$ SE $\frac{1}{4}$ and SE $\frac{1}{4}$ of SW $\frac{1}{4}$	10	59	14	Oct. 16, 1890
D. J. Tew and H. W. Eldrud.....	E $\frac{1}{2}$ SW $\frac{1}{4}$ and SW $\frac{1}{4}$ SW $\frac{1}{4}$..	14	59	14	Oct. 16, 1890
D. J. Tew and H. W. Eldrud.....	NW $\frac{1}{4}$ of NW $\frac{1}{4}$	23	59	14	Oct. 16, 1890
Lewis J. Merritt.....	SW $\frac{1}{4}$ of SW $\frac{1}{4}$	10	58	18	Dec. 16, 1890
Lewis J. Merritt.....	S $\frac{1}{2}$ SW $\frac{1}{4}$ and SW $\frac{1}{4}$ SE $\frac{1}{4}$..	12	58	18	Dec. 16, 1890
Lewis J. Merritt.....	N $\frac{1}{2}$ of SE $\frac{1}{4}$	12	58	18	Dec. 16, 1890
Lewis J. Merritt.....	SW $\frac{1}{4}$ NW $\frac{1}{4}$	2	57	21	Dec. 16, 1890
Lewis J. Merritt.....	NW $\frac{1}{4}$ NE $\frac{1}{4}$	8	57	21	Dec. 16, 1890
Emil Hartmann.....	NE $\frac{1}{4}$	16	59	14	Dec. 26, 1890
Emil Hartmann.....	NW $\frac{1}{4}$	16	59	14	Dec. 26, 1890
Emil Hartmann.....	SW $\frac{1}{4}$	16	59	14	Dec. 26, 1890
Emil Hartmann.....	W $\frac{1}{2}$ SE $\frac{1}{4}$	16	59	14	Dec. 26, 1890
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	NE $\frac{1}{4}$	36	56	25	Jan. 13, 1891
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	NW $\frac{1}{4}$	36	56	25	Jan. 13, 1891
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	SW $\frac{1}{4}$	36	56	25	Jan. 13, 1891
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	SE $\frac{1}{4}$	36	56	25	Jan. 13, 1891
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	SW $\frac{1}{4}$	1	56	23	Jan. 13, 1891
James H. Baker, Fan- nie A. Griffen and Millie W. Griffen....	SE $\frac{1}{4}$ of NW $\frac{1}{4}$	1	56	23	Jan. 13, 1891

To Whom Leased.	Parts of Sections.	Section.	Township	Range.	Date.
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	SW $\frac{1}{4}$ SW $\frac{1}{4}$	2	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	W $\frac{1}{2}$ SE $\frac{1}{4}$, SW $\frac{1}{4}$ NE $\frac{1}{4}$ and SE SW $\frac{1}{4}$	3	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	NW $\frac{1}{4}$ NE $\frac{1}{4}$, W $\frac{1}{2}$ NW $\frac{1}{4}$ and SE $\frac{1}{4}$ NW $\frac{1}{4}$	8	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	E $\frac{1}{2}$ SE $\frac{1}{4}$	8	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	S $\frac{1}{2}$ SW $\frac{1}{4}$ and S $\frac{1}{2}$ SE $\frac{1}{4}$	9	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	SE $\frac{1}{4}$	10	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	S $\frac{1}{2}$ NW $\frac{1}{4}$ and N $\frac{1}{2}$ SW $\frac{1}{4}$	3	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	SW $\frac{1}{4}$ NW $\frac{1}{4}$ and NW $\frac{1}{4}$ of SW $\frac{1}{4}$	10	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	N $\frac{1}{2}$ NE $\frac{1}{4}$, NE $\frac{1}{4}$ NW $\frac{1}{4}$ and W $\frac{1}{4}$ of NW $\frac{1}{4}$	10	56	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	NW $\frac{1}{4}$	23	57	22	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	S $\frac{1}{2}$ NW $\frac{1}{4}$	24	57	22	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	E $\frac{1}{2}$ SE $\frac{1}{4}$	24	57	22	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	S $\frac{1}{2}$ SE $\frac{1}{4}$, S $\frac{1}{2}$ SW $\frac{1}{4}$	29	57	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	N $\frac{1}{2}$ SW $\frac{1}{4}$, SW $\frac{1}{4}$ SW $\frac{1}{4}$	23	57	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	W $\frac{1}{2}$ NE $\frac{1}{4}$	23	57	23	Jan. 13, 1891
James H. Baker, Fannie A. Griffen and Millie W. Griffen....	E $\frac{1}{2}$ SE $\frac{1}{4}$ and E $\frac{1}{2}$ NE $\frac{1}{4}$	12	56	23	Jan. 13, 1891
Henry G. Ingerson....	NE $\frac{1}{4}$	36	58	20	Feb. 9, 1891
Henry G. Ingerson....	NW $\frac{1}{4}$	36	58	20	Feb. 9, 1891
Henry G. Ingerson....	SW $\frac{1}{4}$	36	58	20	Feb. 9, 1891
Henry G. Ingerson....	SE $\frac{1}{4}$	36	58	20	Feb. 9, 1891

PART VII.

LEGISLATION RELATING TO MINERAL LANDS IN MINNESOTA.

Congress enacted in 1866, 1870 and 1872, an elaborate scheme of regulations for the mineral lands of the Pacific slope and the western interior portions of the United States, but its provisions were made not to apply to the states of Michigan, Wisconsin and Minnesota, which were "declared free and open to exploration and purchase, according to legal sub-divisions, in like manner as before the tenth day of May, 1872. And any bona fide entries of such lands within the states named, since the tenth day of May, 1872, may be patented without reference to any of the foregoing provisions of this chapter. Such lands shall be offered for public sale in the same manner, at the same minimum price, and under the same rights of pre-emption as other public lands."*

All the lands of the state, therefore, are subject to the laws that have been enacted for "agricultural lands." When a public survey and sub-division of any township has been made, all its lands are divided into three classes: 1. School lands, comprising sections 16 and 36; 2. Agricultural lands, and 3. Swamp lands. Those lands which are wet and are returned as "swamp lands" by the surveyors, are by law ordered to be patented to the state, and the state may dispose of them as it chooses. In Minnesota large quantities of these lands have been granted to railroad corporations. Special acts of congress have allowed to the state others of the original agricultural lands. Such lands, when patented, become "state lands," and are known as University lands, Agricultural College lands, Salt Spring lands, Capitol lands, etc. The remainder of the original agricultural lands, held by the United States are subject to sale, homestead or other disposition according to the

*The present laws for the disposition of the mineral lands of the United States are found in chapter 6 of the revised statutes, title: "Mineral Lands and Mining resources," and in the regulations of the general land office of date April 1, 1879.

laws of the United States. Some of them have been granted to railroads, and in Michigan many in the northern peninsula were patented to the company which built the Sault Ste. Marie canal. Application respecting the lands of the United States within the state of Minnesota should be made to the registers of the various land offices. For the iron regions of Minnesota the register's office is at Duluth.

The State of Minnesota, having come into possession, through the operation of the laws and grants of congress, of lands on which were found to be valuable deposits of iron, and of silver and copper, found it necessary, in order to protect its prospective revenue interests in these lands, to enact some regulations for their sale or lease. The legislature of 1889 therefore passed the following:

ACT REGULATING THE SALE AND LEASE OF MINERAL AND OTHER LANDS BELONGING TO THE STATE.

SECTION 1. The commissioner of the land office of the State of Minnesota is hereby authorized to execute leases and contracts for the mining and shipping of iron ore, from any lands now belonging to the state, or from any lands to which the state may hereafter acquire title, subject to the conditions hereinafter provided.

SEC. 2. The application for a mineral lease, as herein provided, shall be in such form as the state land commissioner may prescribe. It shall correctly describe the land desired to be leased, and shall consist of contiguous descriptions, which, in the aggregate, shall not exceed one hundred and sixty (160) acres in any one lease, unless some of the descriptions shall be fractional subdivisions, in which case the acreage may exceed the number above mentioned. Before any lease shall be granted, the applicant shall pay to the state treasurer the sum of twenty-five dollars (\$25), and in case two or more persons shall apply for a lease at the same time, then, the one who will pay the largest sum of money therefor, shall be entitled to receive the lease first, provided for in this act.

Provided further, That in case any persons, whether as owners, lessees or otherwise, shall have sunk, or shall hereafter sink mining shafts, or make other mineral developments, to the amount of not less than \$5,000 in good faith under the presumption that the lands belonged to them, or that they had full legal right to operate thereon for iron ore or other minerals, which shall be ascertained to be upon lands belonging to the state or leased under the provisions of this act, such persons shall have a first or prior claim, on the terms above provided, to such development and to a reasonable area of land to embrace and include such improvements.

The holder of a mineral lease, secured as above provided, shall have the right to prospect for iron ore on the lands embraced therein, for a period of one year from the date thereof, at which time said right shall terminate. Provided that no iron ore shall be removed therefrom until a contract, as hereinafter provided, shall have been executed.

SEC. 3. At any time prior to the expiration of said lease, the lease-holder, or any assignee thereof, shall have the right to obtain from the said commissioner of the state land office a contract, which shall bind the state of Minnesota, as the party of the first part, and the person, persons or corporation to whom said contract shall issue, as a party of the second part, in a mutual observance of the obligations and conditions as specified therein.

SEC. 4. The contract provided for in section three (3) shall be as follows:

This indenture, made this....day of...., A. D., one thousand eight hundred and...., by and between the State of Minnesota, party of the first part, and....., party of the second part, *Witnesseth,* That the party of the first part in consideration of the sum of one hundred dollars (\$100) to it in hand paid by

the party of the second part, being the first annual payment hereinafter provided for, the receipt whereof is hereby acknowledged, and in further consideration of the covenants and conditions herein contained, to be kept and performed by the part... of the second part, does hereby contract, lease and demise to the part... of the second part for a term of fifty (50) years from and after the... day of..., one thousand eight hundred and..., the following described land situated in the county of..., in the state of Minnesota, viz:, which premises are leased to the part... of the second part for the purpose of exploring for, mining, taking out and removing therefrom the merchantable shipping iron ore, which is, or which hereafter may be found on, in, or under said land, together with the right to construct all buildings, make all excavations, openings, ditches, drains, railroads, wagon roads and other improvements upon said premises which are or may become necessary or suitable for the mining or removal of iron ore from said premises, with the right, during the existence of this lease, to cut and use the timber found upon said premises for fuel, other than for smelting purposes, and so far also as may be necessary for the construction of buildings required in the operation of any mine or mines, on the premises hereby leased, as also the timber necessary for drains, tramways and supports for such mine or mines. Provided, however, that the part... of the second part shall have the right at any time to terminate this agreement in so far as it requires the part... of the second part to mine ore on said land, or to pay a royalty therefor, by giving written notice to the party of the first part, which shall be served by leaving the same with the commissioner of the state land office, who shall officially in writing acknowledge the receipt of said notice, and the foregoing lease shall terminate sixty (60) days thereafter, and all arrearages and sums which may be due under the same up to the time of its termination, as set forth in such notice, shall be paid upon settlement and adjustment thereof.

The party of the first part further agrees that the part... of the second part shall have the right under this agreement to contract with others to work such mine or mines, or any part thereof, or to sub-contract the same, and the use of said land, or any part thereof for the purpose of mining for iron ore with the same rights and privileges as are herein granted to the said part... of the second part. The part... of the second part in consideration of the premises, hereby covenants and agrees to and with the party of the first part, that the part... of the second part will, on or before the twentieth (20th) days of April, July, October and January, in each year, during the period hereinbefore stipulated, or during the period this contract continues in force, pay to the treasurer of the state of Minnesota, for all the iron ore mined and removed from said land during the three (3) months preceding the first day of the month in which payment is to be made, as aforesaid, at the rate of 25 cents per ton for all the iron so taken out, mined and carried away, each ton to be reckoned at twenty-two hundred and forty (2240) pounds.

The part... of the second part, at the time of such payment, shall transmit to the commissioner of the state land office an exact and truthful statement of the amount of iron ore removed during the three months for which such payment shall be made. The iron ore so taken by the part... of the second part from said land shall be weighed by the railroad company transporting the same from said land, which weight shall determine the quantity as between the parties hereto. Said part... of the second part shall furnish the commissioner of the state land office monthly statements showing the aforesaid weights; the right, however, is hereby conceded to the said party of the first part, by its duly authorized agents, to inspect, review, and test the correctness of said railroad company's scales and weights, at any time and in such manner as may seem proper to adopt, it being understood that any errors in these respects, when ascertained, shall be recognized and corrected. The part... of the second part agrees to pay all taxes, general or specific, upon the land so leased which may be assessed, either against such land and the improvements thereon, or the iron ore product thereof, or any personal property at said mines, during the continuance of this lease; just the same as though the lands herein leased were owned in fee by the said part... of the second part, and at the termination of this lease to quietly and peaceably surrender the possession of said land to the party of the first part.

The part... of the second part further covenants that within five (5) years

from the completion of a railroad within one mile of said land there shall be mined and removed therefrom at least one thousand (1,000) tons of iron ore, and that at least five thousand (5,000) tons shall be annually, thereafter, mined and removed therefrom, and in case the said part . . . of the second part shall not annually remove from said land the five thousand (5,000) tons of ore as above stipulated, the part . . . of the second part shall pay into the treasury of the state of Minnesota a royalty of 25 cents per ton on 5,000 tons, which payment shall be made quarterly as above specified.

Provided further, that up to the time when the first one thousand (1,000) tons of iron ore is required to be mined and removed, as hereinbefore specified, there shall be annually paid into the treasury of the state of Minnesota, by the part . . . of the second part, the sum of one hundred dollars (\$100.00), which payment shall be made on or before the first day of August of each year.

It is mutually understood and agreed that upon the termination of this agreement, whether by the acts of the parties, or either of them, or by limitation, the part . . . of the second part shall have ninety days in which to remove all engines, tools, machinery, railroad tracks and structures erected or placed by said part . . . on said land, but shall not remove or impair any supports placed in the mines, nor any timbers or frame work necessary to the use and maintenance of shafts or other approaches to the mines or tramways within the mines.

The part . . . of the second part shall open, use and work the said mines in such manner only as is usual and customary in the skillful and proper mining operations of similar character when conducted by the proprietors themselves on their own lands, and so as not to do, cause, or permit, any unnecessary or unusual permanent injury to the same, or inconvenience or hindrance in the subsequent operating of the said mine, and in the working of said mine, the part . . . of the second part shall deposit all earth, rock, and other useless material or rubbish at such places and in such manner as will not conflict with or embarrass the future operating of said mines.

The party of the first part expressly reserves to itself (and the part . . . of the second part assents thereto) the right, by its duly authorized agents, to enter into and upon the above described premises and any part or parts thereof, at any time or times, to inspect and survey the same, and measure the quantity of ores that shall have been mined and removed therefrom, not unnecessarily or unreasonably hindering or interrupting the operations of lessees.

The covenants, terms and conditions of this lease shall run with the land and be in all respects binding and operative upon all sub-leases and guaranties under the part . . . of the second part.

It is further provided that the present lease is granted upon the express condition that if the said royalty, or any part thereof, be and remain unpaid after the days and time herein specified, and if the same remain in default for a period of sixty (60) days, or in case the part . . . of the second part fail to keep and perform any of the covenants or conditions herein expressed to be kept and performed by said part . . . of the second part, then and from thenceforth and in either of those events, it shall be lawful for the part . . . of the first part, at its own option, to take possession of the said leased premises with or without any previous notice or process whatever, to re-enter, and the same to have and possess again, as fully and completely as though no lease had been given to the said part . . . of the second part, and they and all parties claiming under them shall be wholly excluded therefrom.

The part . . . of the first part reserves and shall at all times have, possess and hold a lien upon all ore mined, and on all improvements made on said premises by the part . . . of the second part for any unpaid balances due on this contract.

The part . . . of the first part reserves the right to grant to any person or corporation the right of way necessary for the construction and operation of one or more railroads over or across the land herein leased, without let or hindrance from the part . . . of the second part; but such railroad or railroads shall not manifestly or materially interfere with the mining operations carried on, on said premises.

SEC. 5. All payments under this act shall be made to the state treasurer on the order of the state auditor, and shall be credited to the permanent fund of the class of land to which it properly belongs.

SEC. 6. The land commissioner is hereby authorized and empowered, in case the lessee under any lease hereinbefore provided for fails or neglects to fully comply with all the conditions and covenants of such lease, to at once enter upon the premises described in such lease and take possession of the same, any rule of law or equity to the contrary notwithstanding.

SEC. 7. Should copper or any other valuable mineral be discovered on any land leased as heretofore authorized, the terms and conditions on which the same may be mined shall be agreed upon by the state land commissioner and lessee, and in case they are unable to agree, then each shall choose a referee—the two persons thus selected shall choose a third. The decision of said board shall be final and binding on the parties in interest.

SEC. 8. The state land commissioner is hereby authorized to lease state lands for hay or grass privileges, subject to such restrictions as he may prescribe; provided that no such lease shall be for more than one (1) calendar year.

SEC. 9. Wherever state lands situated in the counties of St. Louis, Lake and Cook are sold, for which contracts or patents are issued, it shall be proper for the land commissioner of the state land office to endorse across the face of such contracts or patents the following words: "All mineral rights reserved to the state." The effect of such endorsement shall be to reserve to the state all mineral rights.

SEC. 10. This act shall take effect and be in force from and after its passage.

On these favorable terms 153 leases* have been issued under section 2 of the above law, and under section 3 of the same six contracts, bringing into the state treasury \$4,425. Applications have been made for over 600 leases. About two-thirds of the applications are on the Mesabi range, between the line of the Duluth & Iron Range railroad and the Duluth and Winnipeg railroad. Leases have been issued upon the Vermilion range as far west as Town 47 of Range 125, Fifth Meridian. The major portion of these leases have been taken out for the purpose of exploring for iron ore, although it is reported that a few of them have been issued for silver and copper.

The form generally adopted by the fee owner, for giving an individual or company the privilege to explore on their lands is in shape of an option.

The option gives the individual or company the right to go on to the property described and explore for mineral. There are a great many different forms, but the one almost universally used by the larger land companies allows the explorer to erect suitable camps, use all timber necessary with the exception of pine, hemlock and cedar, for building and shaft timbering, and to sink test-pits and shafts wherever they desire, requiring them to employ a certain number of men continuously and agreeing to grant to the operating company a lease for a term of years, after a certain amount of ore has been shown up. This lease generally requires the mining company to pay a royalty, ranging from 25 cents to 50 cents per ton, on all ore mined.

The Salt Spring lands of the state, received from the United States on the admission of the State into the Union, were devoted,

*For list of these leases see page 350.

in 1873, to the maintenance of the geological and natural history survey of the state, and are managed and sold by the board of regents of the state university.

SUMMARY OF CANADIAN MINING REGULATIONS.

•The following is a summary of the regulations with respect to the manner of recording claims for *mineral lands*, other than coal lands, and the conditions governing the purchase of the same:

Any person may explore vacant Dominion Lands not appropriated or reserved by government for other purposes, and may search therein, either by surface or subterranean prospecting, for mineral deposits, with a view to obtaining a mining location for the same, but no mining location shall be granted until actual discovery has been made of the vein, lode or deposit of mineral or metal within the limits of the location of claim.

A location for mining, except for *iron* or *petroleum*, shall not be more than 1,500 feet in length, nor more than 600 feet in breadth. A location for mining *iron* or *petroleum* shall not exceed 160 acres in area.

On discovering a mineral deposit any person may obtain a mining location, upon marking out his location on the ground, in accordance with the regulations in that behalf, and filing with the agent of Dominion lands for the district within sixty days from discovery, an affidavit in form prescribed by mining regulations, and paying at the same time an office fee of five dollars, which will entitle the person so recording his claim to enter into possession of the location applied for.

At any time before the expiration of five years from the date of recording his claim, the claimant may, upon filing proof with the local agent that he has expended \$500 in actual mining operations on the claim, by paying to the local agent therefor \$5 per acre cash and a further sum of \$50 to cover the cost of survey, obtain a patent for said claim as provided in the said mining regulations.

The Ontario Legislature has made still more liberal laws relating to the acquisition of unsurveyed mineral lands, as may be seen from the following summary of the provisions of the General Mining Act of the Province of Ontario (R. S. O. Cap. 29).

Any person or persons may explore for mines or minerals on any Crown lands, surveyed or unsurveyed, not marked or staked out or occupied.

The price of lands sold as mining locations is two dollars per acre, the pine timber being reserved to the Crown. Patentees or those claiming under them may cut and use such trees as may be necessary for building, fencing or fuel, or for any other purpose essential to the working of mines.

Mining locations in unsurveyed territory shall be rectangular in shape, and the bearings of the outlines thereof shall be due north and south and due east and west astronomically, and such locations shall be one of the following dimensions, viz., eighty chains in length by forty chains in width containing 320 acres, or forty chains square, containing 160 acres, or forty chains in length by twenty chains in width, containing 80 acres.

All such locations must be surveyed by a Provincial Land Surveyor, and be connected with some known point or boundary at the cost of the applicant, who must file with a plication, surveyor's plan, field notes and description of location applied for.

In all patents for mining locations a reservation of five per cent of the acreage is made for roads.

Lands patented under the Mining Act are free from all royalties or duties in respect to any ores or minerals thereon and no reservation or exception of any mineral is made in any patents.

PART VIII.

GLOSSARY OF MINING AND GEOLOGICAL TERMS.

[These terms are selected from glossaries published in Volume IX, *Trans. Am. Inst. Min. Eng.*, by Dr. R. W. Raymond; in Balch's *Mines, Miners and Mining Interests of the U. S.* and in the Report of the Royal Commission upon the *Mineral Resources of Ontario*, and other sources. Some terms have been added that have been met with only among the miners of Minnesota.]

- Accessory minerals**—Minerals found in crystalline rocks in such small proportions that their absence would not alter the lithological name of the rock.
- Acid rock**—A rock containing 55 per cent. or more of silica as opposed to *basic rock* in which the alkaline bases predominate.
- Adit**—A nearly horizontal passage from the surface, by which a mine is entered and drained.
- Aerolites**—Meteoritic masses of metallic or other mineral substances which have fallen to the earth through the air. The metallic aerolites consist principally of metallic iron, nickel and chromium, and the non-metallic of crystalline minerals, and resemble greenstones; others consist of mixtures of these.
- Agglomerate**—An accumulation of more or less rounded fragments of rock in an old volcanic vent or immediately connected with a volcano, the rounding having been caused by friction in the volcano or in the air, and not by the action of water as in the case of a conglomerate.
- Albite**—Soda feldspar; a silicate of alumina and soda, crystallizes in triclinic system.
- Alluvium**—Recent aqueous deposits of silt or mud.
- Alumina**—Oxide of aluminum. Pure crystalline alumina is represented by corundum, sapphire and ruby. The commonest form of alumina is as a silicate, of which clays are mostly composed, and as the compound silicates of aluminum and other metals, of which a very large class of minerals is formed.
- Amalgam**—A combination of mercury with another metal, especially gold or silver.
- Amalgamation**—The process of uniting mercury with gold, silver, etc.
- American forge**—See *Catalan forge*.
- Amorphous**—Without form; applied to rocks and minerals having no definite structure.
- Amphibolite**—See *Hornblende*.
- Amygdales**—An igneous rock containing almond-shaped kernels of minerals such as quartz or agate, calcspar, etc., which have resulted from the filling up of vesicular cavities that originally existed in these rocks due to the expansion of gases in them while still hot and in a soft condition.
- Anorthite**—Lime-feldspar; a silicate of alumina and lime: crystallization triclinic.
- Anthracite**—See *Coal*.
- Anticlinal**—The line of a crest, above or under ground, on the two sides of which the strata dip in opposite directions. The converse of *synclinal*.
- Apatite**—Mineral phosphate of lime. It is usually of various shades of green and bluish green, brownish red and light gray. It occurs in grains and small crystals in nearly all trappean rocks, in granites, gneiss, etc. It represents the fifth degree in the hardness of minerals.
- Apex**—In the U. S. Revenue Statutes, the end or edge of a vein nearest the surface.
- Aqueous**—See *Sedimentary*.
- Arch**—1. A portion of a lode left standing when the rest is extracted, to support the hanging wall, or because it is too lean for profitable extraction.
2. The roof of a reverberatory furnace.
- Archæan**—A term proposed by Dana and largely adopted for the Azoic period or age, or what had formerly been called the primitive rocks, the lowest of the five grand divisions or periods of geological time. It embraces the Laurentian and Keewatin formations, (the Huronian also, according to some geologists), all of which rocks are sometimes called the pre-Cambrian. See *Azoic, Laurentian* and *Huronian*.
- Arenaceous**—Sandy rocks composed of sand or containing sand along with other ingredients.
- Argentiferous**—Containing silver.
- Argentite**—Sulphide of silver; contains 86½ per cent of silver and 13½ of sulphur; heavy blackish gray in color, malleable, easily cut by a knife; it is an important ore of silver, common in the Thunder Bay silver region.
- Argillaceous**—Containing clay, either soft or hardened, as in shale, slate, argillite, etc.
- Arm**—The inclined member or leg of a set or frame of timber.
- Artesian Wells**—Deep wells bored through the solid strata. In properly selected situations the water generally rises in them to the surface, or flows over.

- Asbestos**—A fibrous, flexible variety of hornblende. Chrysotile, a fibrous variety of serpentine is also called asbestos. It fuses at a lower temperature, but for steam-packing answers the same purpose.
- Ascension-theory**—The theory that the matter filling fissure veins was introduced in solution from below.
- Assay**—To test ores and minerals by chemical or blow pipe examination; said to be in the *dry way* when done by means of heat (as in a crucible), and in the *wet or humid way* when by means of solution and precipitation or liquid tests. An assay differs from a complete *analysis* in being confined to the determination of certain ingredients, the rest not being determined. Both assays and analyses may be either qualitative or quantitative; that is, they may determine the presence merely, or also the amount of some or all of the constituents of the substance examined.
- Attle**—Refuse rock.
- Auget or Augette**—A priming tube, used in blasting.
- Auriferous**—Containing gold.
- Azoic**—Without life. Applied to all the ancient crystalline rocks, because they show no evidence of the existence of life on the earth at the time of their formation.
- Back**—With reference to an adit, drift or stope, the part of the ore deposit between it and the next working above, or the surface. 2 See *Face*.
- Back-shift**—The second set of miners working in any spot each day.
- Back-skin**—A leather covering worn by men in wet working.
- Bait**—A pitman's provisions.
- Balling**—The aggregation of iron in the *puddling* or *blowing* process into *balls* or *lumps*.
- Bank**—An ore-deposit worked by surface excavations or drifts above water-level.
- Bar**—1. A drilling or tamping rod. 2. A vein or dyke crossing a lode.
- Barney**—A small car attached to a cable, used to pull cars up a slope or inclined plane.
- Barrel**—A piece of small pipe inserted in the end of a cartridge to carry the *squib* to the powder.
- Barrier-pillars**—Pillars of ore, larger than usual, left at intervals to prevent too extensive crushing when the ground comes to be *robbed*.
- Barrow**—1. A heap of *attle* or rubbish; a *dump*. 2. A vehicle in which ore, rock, etc., are wheeled.
- Barytes**—Sulphate of barium; also called heavy spar, from its high specific gravity. When finely ground it is used as a substitute for white lead paint. It occurs as a veinstone and is abundant in some of the veins between Thunder bay and Pigeon point.
- Basalt**—Igneous rock having a columnar structure like that of the Giants' Causeway in Ireland. Lithologically, basalt is closely allied to diabase.
- Base Metals**—The metals not classed as *noble* or *precious*.
- Basic**—1. In furnace practice, a slag in which the earthy bases are in excess of the amount required to form a neutral slag with the silica present. 2. In geology, a rock which contains less than 55 per cent of silica.
- Basic-lining process**—An improvement of the *Bessemer process*, in which by the use of a basic lining in the *converter* and by the addition of basic materials during the *blow*, it is possible to eliminate phosphorus from the pig-iron, and keep it out of the steel.
- Basin**—1. A natural depression of strata containing a coal bed or other stratified deposit. 2. The deposit itself.
- Basque**—A lining for crucibles or furnaces; generally a compound of clap, etc., with charcoal dust.
- Basset**—"An outcrop;" the edge of a stratum.
- Bath**—A mass of molten material in a furnace, or of a solution in a tank.
- Battery**—"A bulk-head of timber."
- Bearing**—See *Strike*.
- Bed**—A layer of rock or mineral later in origin than the one below, and older than the one above; a regular member of the deposit and not an intrusion.
- Bedded-vein or Bed Vein**—A lode occupying the position of a bed, that is, parallel with the stratification, of the enclosing rock.
- Bed-rock**—The solid rock underlying alluvial and other surface formations.
- Bed-way**—An appearance of stratification or parallel marking in granite.
- Bell's dephosphorizing process**—The removal of phosphorus from molten pig-iron in a puddling furnace, lined with iron oxide and filled with a mechanical rabble to agitate the bath. Red-hot iron ore is added. See *Krupp's washing process*.
- Belt**—A term used in the description of the geographic distribution of strata, especially if inclined strata, to indicate a zone or bank of a particular kind as exposed on the surface.
- Bessemer iron**—Pig-iron suitable for the Bessemer process.
- Bessemer ore**—Iron ore suitable for making steel by the Bessemer process. See page 187 for full definition.
- Bessemer Process**—The process of decarburizing a bath of molten cast iron by blowing air through it, in a vessel called a *converter*.
- Biche**—A tool ending below in a conical cavity, for recovering broken rods from a bore-hole.
- Billet**—1. Iron or steel drawn from a pile, bloom or ingot into a small bar for further manufacture. 2. A small bloom.
- Bing-ore**—Ore in lumps.
- Bing-hole**—A hole or *shoot* through which ore is thrown.
- Bit**—The cutting end of a boring implement.
- Bitumen**—Mineral pitch; it is composed of carbon and hydrogen.
- Bituminous**—Containing disseminated bitumen or its elements, which may generally be distinguished by the dark color or the odor.
- Bitterspar**—Also called *Pearlspar*. The crystalline form of carbonate of lime and magnesia; the pure form of dolomite. It consists of one part or equivalent of carbonate of lime and one of carbonate of magnesia.

- Black-band**--An earthy carbonate of iron, accompanying coal-beds. Worked in Great Britain, Ohio and Pennsylvania.
- Black-damp**--Carbonic acid gas.
- Black-jack**--Dark varieties of zinc blende or sulphide of zinc. It has a resinous lustre and yields a light colored streak or powder.
- Black-lead**--Graphite.
- Black sand**--Heavy particles of black oxides of iron, sometimes accompanied by alluvial gold.
- Blast**--1 The operation of *blasting*, or rending rock or earth by means of explosives. 2 The air forced into a furnace to accelerate combustion. 3 The period during which a blast furnace is in *blast*, that is in operation.
- Blast furnace**--A furnace, usually a shaft-furnace, into which air is forced under pressure.
- Blasting-stick**--A simple form of fuse.
- Blende**--Without any qualification means zinc blende or the sulphide of zinc which has the lustre and often the color of common resin, and yields a white streak and powder. The darker varieties are called black-jack by the English miners. Other minerals having this lustre are also called blendes, as antimony-blende, ruby-blende, pitch-blende, hornblende.
- Blind level**--1. A level not yet connected with other workings. 2. A level for drainage, having a shaft at either end, and acting as an inverted siphon.
- Blind-shaft**--See *Winze*.
- Bloat**--A hammer swelled at the *eye*.
- Blood-stone**--A dark green variety of chert or jasper with small red spots.
- Bloom**--1. A large steel bar, drawn from an ingot for further manufacture. 2. A rough bar of iron, drawn from a catalan or bloomy ball, for further manufacture. See *Billet*.
- Bloomary**--A forge for making wrought-iron, usually directly from the ore. The sides are iron-plates, the *hair-plate*, at the back, the *cinder-plate* at the front, the *tuyere-plate*, through which the tuyere passes, at one side (its upper part being called in some bloomaries the *merrit-plate*.) the *fore-spar-plate* opposite the *tuyere-plate*, its upper part being the *skew-plate*, and the *bottom-plate* at the bottom.
- Blossom**--The oxidized or decomposed outcrop of an ore deposit or coal-bed. Also called *smut* and *tailing*. See *Gossan*.
- Blow**--A single heat or operation of the Bessemer converter.
- Blower**--1. A strong discharge of gas from a fissure. 2. A fan or other apparatus for forcing air into a furnace or mine.
- Blow-in**--To put a blast furnace in operation.
- Blow-out**--1. To put a blast furnace out of blast, by ceasing to charge fresh materials, and continuing the blast until the contents of the furnace have been smelted. 2. A large outcrop, beneath which the lode contracts is called a *blow-out*. 3. A shot or blast is said to be a *blow-out* when it goes off like a gun and does not shatter the rock.
- Boj iron ore**--A loose, earthy brown hematite, of recent origin, formed in swampy ground.
- Bonnet**--A covering over a cage to shield it from objects falling down the shaft.
- Boot**--A leather or tin joint connecting the *blast-main* with the *tuyere* or *nozzle* in a bloomary.
- Board-and-pillar**. See *Post-and-stall*.
- Borer**. See *Drill*.
- Bort**--Opaque black diamond.
- Bosh**--1. A trough in which bloomary tools are cooled. 2. (Or *Boshes*.) The portion of a shaft furnace in which it widens from above the hearth up to its maximum diameter.
- Bottomer**--The man stationed at the bottom of a shaft in charge of the proper loading of cages, signals for hoisting, etc.
- Boulder** or *Boulder*--A fragment of rock brought by moving water or ice from a distance, usually rounded by attrition.
- Bowke**--A small wooden box in which iron ore is hauled under ground.
- Box-bill**--A tool used in deep boring for slipping over and recovering broken rods.
- Box-timbering**. See *Plank-timbering*.
- Brace**--The platform, collar or landing at the mouth of a shaft.
- Brace-head**--A cross-attachment at the top of the column of rods in a deep boring, by means of which the rods and bit are turned after each drop.
- Brakesman**--The man in charge of a hoisting engine.
- Branch**--A small vein or elbow departing from the main lode, and in some cases returning.
- Brasses**--Pyrites.
- Brattice**--A plank lining, or a longitudinal partition of wood, brick, or even cloth, in a shaft, level or gangway, generally to aid ventilation.
- Brazil**--Iron pyrites.
- Breast**--1. The face of a working. 2. The chamber driven upwards from the gangway, on the ore deposit, between pillars left standing. 3. That side of the hearth of a shaft furnace which contains the *metal-notch*.
- Breast-boards**--Planking placed between the last set of timbers and the face of a gangway or heading which is quicksand or loose ground.
- Breccia**--A conglomerate in which the fragments are angular.
- Brülle-chains**--Safety-chains to support a cage if the link between the cage and rope should break.
- Brob**--A peculiar spike, driven alongside the end of an abutting timber to prevent its slipping.
- Browse**--Ore imperfectly smelted, mixed with cinder and clay.
- Bucker**--A flat piece of iron with a wooden handle used for breaking ore.

- Bucking**—See *Cobbing*. The *bucking-hammer* or *bucking-iron* is a broad-headed hammer used for bucking or breaking ore; the ore is broken on a flat piece of iron called the *bucking-plate*.
- Buckshot cinder**—Cinder from the iron blast furnace, containing grains of iron.
- Buddle**—A circular tub, pit or enclosure for separating finely divided ores from the waste by means of water.
- Bulkhead**—A tight partition or stopping in a mine for protection against water, fire or gas.
- Bulldog**—A refractory material used as a furnace-lining, obtained by calcining *mill-cinder*, and containing silica and ferric oxide.
- Bullfrog**—See *Barney*.
- Bull-pump**—A direct single-acting pump, the steam cylinder of which is placed over the top of a shaft or slope, and the piston-rod attached to the pump-rods. The steam lifts piston and pump-rods, and their own weight produces a down-stroke.
- Bull wheel**—A wheel on which is wound the hoisting cable.
- Bully**—A pattern of miner's hammer, varying from "*broad-bully*" to "*narrow-bully*."
- Bunch**—In mining, an irregular mass of ore of considerable size.
- Banding**—A staging of boards on *stulls* or *stemples*, to carry *deads*.
- Burden**—The proportion of ore and flux to fuel in the charge of a blast-furnace.
- Burnt iron**—1. Iron which by long exposure to heat has suffered a change of structure and become brittle. It can be restored by careful forging at welding heat. 2d. In the *Bessemer* and *open-hearth* processes, iron which has been exposed to oxidation until all its carbon is gone, and oxide of iron has been formed in the mass.
- Burr**—Solid rock.
- Butt**—A surface exposed at right angles to the *face*. See *End*.
- Bully**—A miner by contract at so much per ton of ore.
- Cabbling**—Breaking up pieces of flat iron to be *piled* or *fagoted*, heated and rolled.
- Cache**—The place where provisions, ammunition, etc., are *cached* or hidden by trappers or prospectors in unsettled regions.
- Cage**—1. A frame with one or more platforms for cars, used in hoisting in a vertical shaft. It is steadied by guides on the sides of the shaft. 2. The barrel or drum in a *whim* on which the rope is wound.
- Cainozoic**—See *Tertiary*.
- Calamine**—The natural carbonate of zinc; one of its most easily reduced ores; occurs both in beds and veins, mostly in the Carboniferous and higher rocks.
- Calcareous**—Containing carbonate of lime as calcareous sandstone, or composed of it, as calcareous spar or *calcspar*.
- Calcareous tufa**—A spongy, porous or vesicular deposit of carbonate of lime from water. It often incrusts vegetable and animal substances, which are thus said to be petrified. When the carbonate of lime, is deposited in a more solid form it is called *travertine* or *calc sinter*. *Stalactites* and *stalagmites* are of this nature.
- Calceriferous**—Carrying carbonate of lime.
- Calcine**—To expose to heat, with or without oxidation; to *roast*, applied to ores for the removal of water and sulphur and carbonic acid, etc.
- Calc-spar**—See *Calcareous*.
- Cam**—A projection from a revolving shaft for raising the stamp by catching the lower surface of the tappit or collar surrounding the rod on which the stamp-head is hung. The upper side of the cam has an easy curve, such as a parabola, so that when it strikes the tappit it may not jar it when the lifting movement begins.
- Cam-shaft**—A strong horizontal revolving shaft to which a number of cams are attached in such a manner that no two of them shall strike the tappits at the same instant, thus distributing the weight to be lifted.
- Cambrian**—Derived from *Cambria*, the ancient name of Wales. The name given by the late professor Sedgwick of the University of Cambridge to the rocks of the second fauna, the *Llandello-Bala* group. His "*Lower Cambrian*" embraced the zone of the *Taconic* of America and the primordial of *Barrande*.
- Canon**—A ravine or gorge, usually on a large scale.
- Cap, or Cap rock**—Barren vein-matter or rock, or a *pinch* in a lode, supposed to overlie ore.
- Captain**—The official in immediate charge of the work in a mine.
- Carbonaceous**—Containing a carbonate or carbon not oxidized.
- Carboniferous System**—The system of rocks which succeeds the Devonian or "*Old Red Sandstone*" and precedes the Permian or New Red Sandstone. It is characterized by its containing workable seams of true coal.
- Carnelian**—One of the varieties of *chalcedony*, originally only the red, but now of any color.
- Case harden**—To convert iron superficially into steel by partial cementation.
- Casing**—A partition or *brattice*, made of *casing-plank*, in a shaft.
- Casting**—Pouring or drawing fused metal from a blast furnace, cupola, crucible, converter, or ladle into moulds.
- Catalan forge**—A forge with a tuyere for reducing iron ore, with charcoal, to a loup of wrought iron; a *bloomery*. See *Champlain forge*.
- Cat-head**—1. A small capstan. 2. A *broad-bully* hammer. See *Bully*.
- Caving**—The falling in of the sides or top of an excavation.
- Celestine or celestite**—Sulphate of strontium, a mineral which resembles barite in its high specific gravity and is often mistaken for it. It may be used for many of the same purposes in the arts.
- Cement**—The calcareous, siliceous, ferruginous, etc., matter, cementing together gravel, broken fragments of rock, etc.
- Cerussite**—Natural carbonate of lead, which sometimes occurs in economic quantities.
- Chafery**—A forge fire for *reheating*.
- Chalcedony**—Translucent varieties of quartz, such as *carnelian*, *agate*, *siliceous sinter*, etc.

- Chalk**--Originally and properly the soft amorphous variety of limestone of the Cretaceous system used for marking, but now also applied to other substances, as red chalk or clayey oxide of iron, French chalk or steatite or soapstone.
- Chalybeate**--Impregnated with iron (applied to waters).
- Champlain forge or American forge**--A forge for the direct production of wrought iron, generally used in the United States instead of the Catalan forge, from which it differs in using only finely-crushed ore and in working continuously.
- Changing-house**--A room where miners change and dry their underground clothing. See *Dry*.
- Charge**--1. The materials introduced at one time or one round into a furnace. 2. The amount of explosive used for one blast.
- Cheeks**--1. The sides or walls of a vein or lode. 2. Extensions of the sides of the eye of a hammer or pick.
- Chenot process**--The process of making iron-sponge from ore mixed with coal-dust, and heated in vertical cylindrical retorts.
- Chert**--A brittle nearly opaque variety of flint. It generally occurs as nodules or thin irregular beds in limestones, and is abundant at the base of the Anniike.
- Chill**--An iron mould or portion of a mould, serving to cool rapidly and so to harden the surface of molten iron which comes in contact with it. Iron which can be thus hardened to a considerable extent is *chilling iron*, and is especially used for cast-iron railway car-wheels requiring hardness at the rim without loss of strength in the wheel.
- Chimney**--An ore-shoot. See *Chute*.
- Chlorite**--A soft, dark green mineral, entering largely into the composition of chloritic schist. It is a silicate of alumina, magnesia and iron, and has a peculiar earthy odor when freshly broken and breathed upon.
- Choke-damp**--Carbonic acid gas.
- Chrome ore**--Chromic iron (chromite, oxide of chromium and oxide of iron.)
- Chute**--(Sometimes written *shoot*.) 1. A channel or shaft underground, or an inclined trough above ground, through which the ore falls or slides from a higher to a lower level. 2. A body of ore, usually of elongated form, extending downward.
- Cinder**--Slag, particularly from iron blast furnaces.
- Cinderpig**--See *Pig iron*.
- Cinder tap, Cinder notch**--The hole through which cinder is tapped from a furnace.
- Cinnabar**--Sulphide of mercury. A very heavy, red, granular crystalline mineral, giving a bright red streak, and easily reduced to metallic mercury.
- Claim**--The portions of mining ground held under the Federal or State laws by one claimant or association, by virtue of one location and record.
- Clastic**--Broken, fragmental; a rock composed of pieces, or of fine grains which have been formed by the breaking down of pre-existing rocks, as opposed to crystalline and other rocks which have been formed from the cooling of molten matter, or from the alteration of sedimentary rocks to such an extent that all traces of an original fragmentary origin are obliterated.
- Clay-Ironstone**--Clayey carbonate of iron. A heavy compact or fine-grained clayey looking stone, occurring in nodules and uneven beds among Carboniferous and other rocks. It contains only 20 to 30 per cent. of metal, and yet much of the iron produced in Great Britain is made from it.
- Cleavage**--The property in a mineral of splitting more easily and perfectly in some directions than in others. The *cleavage* of rock-masses is more properly a jointing, unless it follows the planes of bedding.
- Clinometer**--A simple apparatus for measuring by means of a pendulum or spirit-level and circular scale, vertical angles, particularly *dips*.
- Coal, Anthracite**--Hard, black, composed almost wholly of carbon; *bituminous* or *caking coal*, brownish or black, containing hydro-carbons; and *lignite* or *brown coal*, containing much water.
- Cobbing**--Breaking ore to sort out its better portions. See *Spal*.
- Cleaning Up**--The process of collecting together the metal or ore which has accumulated in the various contrivances for saving it by mining machinery.
- Cobble**--An imperfectly puddled ball, which goes to pieces in the squeezer.
- Cobble stones**--Smooth, flattened, rounded or elongated stones, larger than pebbles and smaller than boulders; used for paving.
- Coffer or Cofer**--A rectangular plank frame, used in timbering levels.
- Coffin**--1. An old open working. 2. The mode of open working by casting up ore and waste from one platform to another, and so to the surface.
- Cog**--To roll or bloom ingots.
- Coil Drag**--A tool to pick up pebbles, bits of iron, etc., from the bottom of a drill hole.
- Coke**--When the bitumen is driven out of coal by heating it out of contact with the air, as in ovens constructed for the purpose, the residue is called coke.
- Cold blast**--Air forced into a furnace without being previously heated.
- Cold short**--Brittle when cold. Applied chiefly to iron and steel containing an excess of phosphorus.
- Collar**--The collar of a shaft is the horizontal timbering around the mouth.
- Color**--Minute particles of gold obtained by panning, and too small for their value to be estimated.
- Combined Carbon**--That portion of the carbon in iron or steel which is not visible as graphite, and is supposed to be alloyed or chemically combined with the iron.
- Complex**--In mineralogy, containing many ingredients, compound or composite. Some United States geologists use the word as a noun to indicate a complex set of rocks folded together, or intricately mixed, involved, complicated or enlarged.
- Concentration**--The removal by mechanical means of the lighter and less valuable portions of ore.
- Conchoidal**--Shell-shaped. The more compact rocks, such as flint, argillite, felsyte, etc., break with concave and convex surfaces and are therefore said to have a conchoidal fracture.

- Concretionary**—Tending to grow together. Particles of like chemical composition, when free to move, come together and form nodules of various sizes and shapes which are called concretions. Clay and ironstone nodules, balls of iron pyrites, turtle stones, etc., are good examples. Some greenstones exhibit concretionary structure.
- Conformable**—When beds or strata lie upon one another in unbroken and parallel order they are said to be conformable, and this arrangement shows that no disturbance or denudation has taken place at the locality while their deposition was going on. But if one set of beds rests upon the eroded or up-turned edges of another, showing a change of conditions or a break between the formations of the two sets of rocks, they are said to be unconformable.
- Conglomerate**—A rock consisting of fragments of other rocks (usually rounded) cemented together.
- Contact**—The plane between two adjacent bodies of dissimilar rock. A *contact-vein* is a vein, and a *contact-bed* is a bed, lying, the former more or less closely, the latter absolutely, along a contact.
- Contemporaneous**—Existing together or at the same time.
- Contorted**—Bent or twisted together. Used where strata are very much folded or crumpled on a considerable scale. If on a small scale they are said to be *corrugated*.
- Contraction**—Shrinking. Rocks in passing from a vitreous to a crystalline texture shrink considerably, which may account for the subsidence of certain areas. The whole globe of the earth has shrunk by cooling. This contraction is supposed to be a cause of volcanic action.
- Converter**—See *Bessemer process*.
- Cornish Pump**—A pump operated by rods attached to the beam of a single-acting condensing steam-engine. The steam, pressing down the piston in the vertical steam-cylinder, lifts the pump-rods, and these subsequently descend by their own weight.
- Corrugated**—When beds on a small scale are much wrinkled, folded or crumpled, they are said to be corrugated. On a larger scale they are said to be contorted.
- Costeaning or Costeening**—Discovering ore-deposits by pits and open cuts, run on the surface transversely to the supposed strike of the ore.
- Country or Country-rock**—The rock traversed by or adjacent to an ore deposit.
- Course**—See *Strike*.
- Coursing**—Conducting the air-current of a mine in different directions by means of doors and stoppings.
- Couthiching**—The name applied by A. C. Lawson to the crystalline schists at Rainy Lake. The Vermilion schists of the Minnesota report.
- Cramp**—A pillar of rock or mineral left for support.
- Creep**—A rising of the floor of a gangway, occasioned by the weight of incumbent strata, in pillar workings. Also any slow movement of mining ground.
- Cretaceous System**—The system of rocks next above the Jurassic, so called from the abundance of chalk which it contains in England. In America the same system as recognized by its fossils holds but little chalk.
- Cribbing**—Close timbering, as the lining of a shaft, or the construction of *cribs* of timber or timber, earth and rock to support a roof.
- Crop**—The *basset* or outcrop of strata at the surface.
- Cross-course**—A vein crossing the general course of a more important one.
- Cross-cut**—A level driven across the course of a vein, or in general, across the direction of the main workings, to connect two parallel gangways.
- Crow or Crow-foot**—A tool with a side-claw, for grasping and recovering broken rods in deep bore-holes.
- Crushing mill**—The same as stamp mill.
- Crusher**—A machine for crushing ores.
- Cryolite**—A soft white translucent mineral which melts in ordinary flame. It consists of fluoride of sodium and aluminum, and is valuable for the manufacture of carbonate of soda, and metallic aluminum. It occurs in veins in gneiss in western Greenland.
- Crystals**—The various geometric forms assumed by nearly all the solid chemical elements and definite compounds, whether natural or formed artificially. The countless modifications of crystalline forms are all grouped under six systems.
- Crystalline rocks**—Consisting of crystalline particles or grains; when the latter are distinct the rock is said to be crystalline-granular.
- Crystallography**—The description or science of crystals.
- Cup-and-Cone**—A machine for charging a shaft-furnace, consisting of an iron hopper with a large central opening, which is closed by a *cone* or *bell* pushed up into it from below. In the annular space around this cone, the ore, fuel, etc., are placed; then the cone is lowered to drop the materials into the furnace, after which it is again raised to close the hole.
- Cupola**—A shaft-furnace with a blast, for remelting metals, preparatory to casting.
- Cupiferous**—Copper-bearing. The Nipigon or Keweenaw formation.
- Curb**—A timber frame, circular or square, wedged in a shaft to make a foundation for walling or tubing, or to support, with or without other timbering, the walls of the shaft.
- Dam**—The wall of refractory material, forming the front of the *fore-hearth* of a blast furnace. It is built on the inside of a supporting iron plate (dam-plate). Iron is tapped through a hole in the dam, and cinder through a notch in the top of the dam.
- Damp**—Miners in England call gas “damps”; carbonic acid gas is choke-damp, and light carburetted hydrogen is fire-damp.
- Dam-plate**—The plate upon the *dam-stone* or front stone of the bottom of a blast furnace.
- Damp-sheet**—A large sheet, placed as a curtain or partition across a gate-road to stop and turn an air-current.

- Dead*—1. Unventilated. 2. As a vein or piece of ground, unproductive.
- Dead ground*—Rock in a mine which, although producing no ore, requires to be removed in order to get at productive ground.
- Deads*—The waste rock, packed in excavations from which ore has been extracted.
- Dead work*—Work that is not directly productive, though it may be necessary for exploration or future production.
- Deal*—Plank used in shaft and gallery timbering.
- Decomposition*—The breaking up or decay of compounds into simpler chemical forms.
- Decrepitation*—The breaking up with a crackling noise of mineral substances when exposed to heat, as when common salt is thrown upon the fire.
- Denudation*—The washing down of surface deposits so as to lay bare underlying formations. This washing away in one place is associated with the *area* of deposition in another.
- Deposit*—Anything laid down. Formerly applied to matter left by the agency of water, but now made to include also mineral matter in any form, and precipitated by chemical or other agencies, as the ores, etc., in veins.
- Derrick*—A hoisting tower or stand.
- Descension-theory*—The theory that the material in veins entered from above.
- Detritus*—Accumulations derived from the wearing down of rock surfaces.
- Devitrification*—The change from a glassy to a crystalline state.
- Devonian system*—The geological system of rocks above the Silurian and below the Carboniferous; so-called from Devonshire. In Scotland it was called the Old Red Sandstone.
- Diabase*—A dark green, greyish green or nearly black igneous rock, one of the greenstones; consisting of a triclinic feldspar, augite (or pyroxene) and usually some olivine, with magnetic or titaniferous iron, apatite and viridite as accessory minerals. It occurs in dykes, beds, overflows and erupted sheets and masses, and it may be coarsely or very finely crystalline. It is common in all the above forms around lake Superior and north of lake Huron. Diabase differs from basalt in having undergone certain internal mineralogical changes, without, however, affecting its general chemical composition, which is the same in both. Some varieties of amygdaloid have the composition of diabase.
- Diagonal stratification*—Also called false bedding and current bedding. Many sands and sandstones are marked by lines of subordinate stratification running through the main beds at various angles to their planes; these are due to currents at the time of deposition, and they have received the above names.
- Dial*—To dial a mine is to make a survey of it.
- Diallage*—A very cleavable variety of augite or pyroxene. Gabbro or diallage rock is composed of this mineral and a triclinic feldspar.
- Diamond-drill*—A form of rock-drill in which the work is done by abrasion instead of percussion; black diamonds (*borts*) being set in the head of the boring tool.
- Diggings*—Applicable to all mineral deposits and mining camps.
- Dike or Dyke*—A vein of igneous rock.
- Diluvium*—Sand, gravel, clay, etc., in superficial deposits. See *drift*.
- Dioryte*—A crystalline igneous or metamorphic rock, outwardly resembling diabase, and also called greenstone, but composed of a triclinic feldspar and hornblende, generally with some magnetite and apatite as accessory minerals. Dioryte occurs in the same manner as diabase, and is a common rock north of the great lakes. There are several varieties of dioryte, the principal of which are quartz-dioryte, containing free quartz, mica-dioryte, containing black mica, often abundantly, dioryte-porphyr or porphyritic dioryte, in which some of the feldspar or hornblende is in the form of large crystals among the smaller ones. Both dioryte and diabase sometimes assume a coarsely concretionary structure.
- Dip*—The inclination of a vein or stratum below the horizontal. The dip at any point is necessarily at right angles with the local *strike*, and its inclination is steeper than that of any other line drawn in the plane of the vein or stratum through that point.
- Disintegration*—The breaking asunder and crumbling away of a rock, due to the action of moisture, heat, frost, air and the internal chemical reaction of the component parts of rocks when acted upon by these surface influences.
- Dislocation*—A shifting of the relative position of the rock on either side of a crack or break. It may be up, down or to one side. Equivalent to slip, slide, fault, throw, heave, upthrow, downthrow.
- Divining-rod or Dowsing-rod*—A rod, most frequently of witch-hazel, and forked in shape, used, according to the old but still extant superstition, for discovering mineral veins, springs of water, oil-wells, etc.
- Divisional planes*—Planes, which divide rocks into separate masses, large or small, in the same way as joints, fissures and backs.
- Doleryte*—A crystalline igneous rock having the composition of basalt and diabase, but formerly supposed to belong to newer rocks. This distinction has not been maintained. The term is now used to distinguish the coarser grained varieties of basalt in which the component minerals may be distinguished by the naked eye.
- Dolomite*—A rock consisting of carbonate of lime and carbonate of magnesia in the proportions of one chemical equivalent of each, also called magnesian limestone. It occurs in a great many crystalline and non-crystalline forms, the same as pure limestone, and among rocks of all geological ages. When calcined it answers for most of the purposes of ordinary lime. But in the caustic form it would be unfit for putting upon land as a manure. When the carbonate of magnesia is not present in the above proportion the rock may still be called a magnesian limestone, but not a dolomite, strictly speaking.
- Dope*—See *Explosives*.
- Downcast*—The opening through which the ventilating air-current descends into a mine.

Downcome—The pipe through which *tunnel-head* gases from iron blast-furnaces are brought down to the hot-blast stoves and boilers, when these are below the *tunnel-head*.

Drag-twist—A spiral hook at the end of a rod, for cleaning bore-holes.

Dressing—The picking and sorting of ores, and washing, preparatory to reduction.

Drift—1. A horizontal passage underground. A *drift* follows the vein as distinguished from a *cross-cut*, which intersects it, or a *level* or *gallery* which may do either.
2. Unstratified *diluvium*, including the till.

Drill—A metallic tool for boring in hard material. The ordinary miner's drill is a bar of steel, with a chisel-shaped end, and is struck with a hammer.

Driving—Extending excavations horizontally. Distinguished from *sinking* and *raising*.

Drum—That part of the winding machine on which the rope or chain is coiled.

Druse—A crystallized crust lining the sides of a cavity.

Dry—See *changing-house*.

Dump—1. To unload a vehicle by tilting or otherwise, without handling or shoveling out its contents. 2. A pile of ore or rock.

Dune—A heap of blown or drifted sand.

Dust-plate—A vertical iron plate, supporting the *slag-runner* of an iron blast furnace.

Dyke, see *Dike*.

Earth's Crust—The external part of the earth, accessible to geological investigation. The use of this term does not necessarily imply that the rest of the earth is not also solid.

Economic Minerals—Any minerals having a commercial value.

Elvan—A granite vein or belt running through schistose rocks.

Emery—Properly a variety of corundum from Cape Emeri in the island of Noxos, but generally used to signify the powder of corundum, a mineral consisting of alumina alone, and ranking next the diamond in hardness.

Engine Shaft—Usually the principal shaft in a mine, and the one at which the hoisting and pumping are done.

Entry—An *Adit*.

Eocene—The oldest division of the Tertiary system. This name was introduced by Sir Charles Lyell, and means the dawn of the recent.

Epidote—A hard mineral, usually of a grass-green or a yellowish green color, common among gneisses, greenstones and certain schists.

Epidiote—An intimate mixture of epidote and quartz, forming an exceedingly tough and hard rock.

Equivalent—Used in geology in regard to rocks of corresponding age in regions far from each other.

Erosion—The gnawing or wearing away of rocks by means of denuding agencies. The disintegrating processes already referred to soften the rocks, which are then removed by the erosive action of ice or water aided by gravitation, etc.

Erratic—A name often given to transported boulders.

Eruption—A violent breaking forth to the surface of pent-up matters, such as lava, volcanic ashes, stones, mud, water, etc.

Escarpment—A perpendicular cliff, especially of stratified rock.

Exfoliate—To fall off in leaves or scales, as some rocks do by weathering. In this way the concretionary structure of some kinds of greenstones is well brought out, the weathered surface showing only rounded masses with the successive layers falling off.

Exploder—A cap or fulminating cartridge placed in a charge of gunpowder or other explosive, and exploded by electricity or by a fuse.

Exploitation—The productive working of a mine, as distinguished from exploration.

Explosives—The principal explosives used in mining are *gunpowder*, a compound of sulphur, charcoal and potassium nitrate or sodium nitrate; *nitro-glycerine*, a liquid compound of carbon, hydrogen, nitrogen and oxygen, produced by the action of nitric acid upon glycerine; *dynamite No. 1* or *giant-powder*, a mixture of nitro-glycerine with a dry, pulverized mineral or vegetable absorbent or *dope* (commonly siliceous or infusorial earth); *dynamite No. 2*, nitro-glycerine mixed with sawdust, saltpeter, coal-dust, paraffin, etc., in lieu of an explosive *dope*; *litho-fracteur*, nitro-glycerine mixed with siliceous earth, charcoal, sodium (and sometimes barium) nitrate and sulphur; *duatin*, nitro-glycerine mixed with potassium nitrate and fine saw-dust; *rend-rock*, *Atlas*, *Hercules*, *tonite*, *vigorite*, with other powders, resembling dynamite No. 2, *i. e.* consisting of nitro-glycerine with a more or less explosive *dope*; and *mica-powder*, a *No. 1 dynamite*, in which the *dope* is scales of fine mica. The *chlorate*, *picrate* and *fulminate* explosives are not used in mining, except the fulminate of mercury, which is employed for the *caps* or *exploders*, by means of which charges of gunpowder, dynamite, etc., are fired.

Eye—1. The top of a shaft. 2. The opening at the end of a tuyere, opposite the *nozzle*.
3. The hole in a *pick* or hammer-head which receives the handle.

Face—In any adit, tunnel or stope, the end at which work is progressing or was last done.

Fahband—A zone or stratum in crystalline rock impregnated with metallic sulphides.

Fan—A revolving machine, to blow air into a mine (*pressure-fan*, *blower*), or to draw it out (*suction fan*.)

Fang—An air-course cut in the side of a shaft or level, or constructed of wood.

Fast-end—A gang-way with rock on both sides.

Fast-shot—A charge of powder exploding without producing the desired effect.

Fauna—The animals collectively of any given age or region. The plants are similarly called its *Flora*.

Fault—A dislocation of the strata or the vein.

Feeder—A small vein falling into or joining a larger one and often enriching it or otherwise affecting its character.

- Feldspars**—Several allied species of minerals composed of silicates of alumina and of alkalis and lime. They crystallize in different systems. The triclinic group of feldspars is called collectively plagioclase. The principal species of feldspars are orthoclase, albite, labradorite, anorthite and oligoclase. In granitoid rocks the feldspar grains may be detected by the shining of the faces of the cleavage planes. Those of labradorite are marked by minute parallel ridges called striae. The feldspars rank sixth in the scale of hardness, or next softer than quartz, and may be scratched with difficulty by the point of a knife.
- Feldspathic**—Containing feldspar as a principal ingredient.
- Felsyte**—A compact rock composed of orthoclase feldspar and silica in microscopic grains.
- Ferric Furnace**—A high iron blast furnace, in the upper part of which crude bituminous coal is converted into coke.
- Ferromanganese**—An alloy of iron and manganese.
- Ferruginous**—Containing iron.
- Fine Metal**—The iron or plate-metal produced in the refinery.
- Finery**—A charcoal-hearth for the conversion of cast into malleable iron.
- Finng**—1. See *Refining*. 2. The conversion of cast into malleable iron in a hearth or charcoal fire.
- Fire-bricks**—Refractory bricks of fire-clay or of siliceous material used to line furnaces.
- Fire-bridge**—The separating low wall between the fire-place and the *hearth* of a reverberatory furnace.
- Fire-clay**—A clay comparatively free from iron and alkalis, not easily fusible and hence used for fire-bricks. Often found beneath coal-beds.
- Fire-damp**—Light carburetted hydrogen gas. When present in common air to the extent of one fifteenth to one-thirtieth of volume the mixture is explosive.
- Fissile**—Capable of being split, as schist, slate and shale.
- Fissure-vein**—A fissure in the earth's crust filled with mineral.
- Flaggy**—Capable of being split into parallel-faced slabs thicker than slates.
- Flag**—A two-pointed miner's pick.
- Flap-door**—Applied to a man-hole door.
- Flat**—A horizontal vein or ore deposit auxiliary to a main vein; also any horizontal portion of a vein which is not elsewhere horizontal.
- Float-ore**—Fragments of the material of an ore deposit found at a distance from its outcrop.
- Floor**—1. The rock underlying a stratified or nearly horizontal deposit, corresponding to the *foot-wall* of more steeply dipping deposits. 2. A horizontal, flat ore-body.
- Flora**—The plants collectively of a given age or region. See *Fauna*.
- Fluccan**—Soft, clayey matter in the lode.
- Flume**—A wooden trough, sluice or race for conveying water.
- Fluorspar**—Fluoride of calcium; a mineral which often forms veinstone and is usually finely colored,—green, purple, yellow, blue, etc. It is the fourth in the scale of hardness, or next higher than calcite, and may be scratched by a steel point. It crystallizes in the Isometric system. Common in veins in the Animike slates of the Thunder bay district.
- Fluting**—Smooth gutter-like channels or deep smooth furrows worn in the surface of rocks by glacial action.
- Fluviatile**—Pertaining to rivers.
- Flux**—In metallurgy, any substance added to facilitate the smelting of another.
- Foliated**—Leaf-like. The meaning is similar to that of laminated, but the latter is now generally used to indicate a finer or more parallel division into layers, foliation being applied rather to the approximate parallelism of the layers in such rocks as gneiss and schist.
- Foot-wall**—The wall of rock upon which the ore deposit seems to lie.
- Foot-way**—The series of ladders and *sollars* by which men enter and leave a mine.
- Foraminifera**—Minute marine animals of the lowest and simplest organization, but having beautiful shelly coverings.
- Forefield**—The face of the workings. The *forefield-end* is the end of the workings farthest advanced.
- Fore-hearth**—A projecting bay in front of a blast-furnace hearth, under the *tymp*. In open-front furnaces it is from the fore-hearth that cinder is tapped. See *Dam* and *Tymp*.
- Forge**—1. An open or semi-open *hearth* with a *tyure*. 2. That part of an iron works where *balls* are squeezed and hammered and then drawn out into *puddle-bars* by grooved rolls.
- Forge-cinder**—The slag from a forge or bloomery.
- Forepale or forpale**—The drawing of timbers or planks horizontally ahead at the working face, to prevent the caving of the roof in subsequent driving.
- Formation**—"Any assemblage of rocks which have some character in common, whether of origin, age or composition."—*Lyell*. In chronological geology formations constitute as it were the units, and several formations may go to make up a system. The word is often loosely used to indicate anything which has been formed or brought into its present shape.
- Fossil**—Literally anything "dug up," but how restricted to organic remains, and not properly applied to any mere mineral substance.
- Fossil ore**—Fossiliferous red hematite.
- Fracture**—The character or appearance of a freshly broken surface of a rock or mineral. Peculiarities of fracture afford one of the means of distinguishing minerals and rocks from one another.
- Fragmentary rocks**—Rocks composed of fragments, whether large or small, broken from pre-existing ones. See *Clastic*.
- Freestone**—A variety of sandstone which may be freely dressed by the stone-cutter.
- Friable**—Easily broken, or crumbling naturally.
- Fundamental rocks**—Those which form the foundation, substratum, basis or support of others.

Furgen—A round rod used for sounding a bloomy fire.

Furnace—1. A structure in which heat is produced by the combustion of fuel. 2. A structure in which, with the aid of heat so produced, the operations of roasting, reduction, fusion, steam generation, dessiccation, etc., are carried on, or, as in some mines, the *up-cast* air-current is heated to facilitate its ascent and thus aid ventilation.

Fuse—A tube or casing filled with slow burning material, by means of which a blast is ignited and exploded.

Gabbro—An igneous rock consisting of a crystalline granitoid mixture of a triclinic feldspar and diallage, the latter being a variety of augite with perfect cleavage in one direction. Gabbro is often accompanied by, or partially composed of, titaniferous magnetite or ilmenite.

Gad—1. A steel wedge. 2. A small iron punch with a wooden handle, used to break up ore.

Galena—The commonest ore of lead, of which it is the sulphide. When freshly broken it has a bright silvery appearance, from which it has been called lead-glance. It crystallizes in the cubic system. Galena nearly always contains more or less silver; too little to extract profitably in the majority of cases.

Gallery—A level or drift.

Ganister—A mixture of ground quartz and fire-clay used in lining Bessemer converters.

Gang—1. A mine. 2. A set of miners.

Gangue—The mineral associated with the ore in a vein.

Gangway—1. A main level. 2. A wooden bridge.

Gas-furnace—A furnace employing gaseous fuel.

Gash—Applied to a vein wide above, narrow below, and terminating in depth within the formation it traverses.

Gate, Gate-way or Gate-road—1. A road or way underground, for air, water or general passage; a *Gangway*. 2. The aperture in a founder's mould, through which the molten iron enters.

Gear—1. The working tools of a miner. 2. The mechanical arrangement connecting a motor with its work.

Geode—A cavity, studded around with crystals or mineral matter, or a rounded stone containing such a cavity.

Geological Formation—Groups of rocks of similar character and age are called formations. The miners of Minnesota frequently apply the term to the rocks of a particular region and not of a geological period.

Geology—"The science which investigates the history of the earth." *Geikie*.

Giraffe—A car of peculiar construction to run up an incline.

Grth—In *square-set* timbering, a horizontal brace in the direction of the *drift*.

Glacier—A large accumulation of ice formed from snow falling upon high land and gradually sliding to lower levels. When a glacier reaches the sea it gives rise to icebergs.

Glance—A term formerly used to designate various minerals having a splendid lustre, as silver-glance, lead-glance, etc. These minerals are generally the sulphides of the metals so termed.

Gneiss—A foliated crystalline rock of a general granitoid composition. The commonest varieties are mica-gneiss, consisting of feldspar, quartz and mica, and hornblende gneiss, or syenite gneiss, consisting of feldspar, quartz and hornblende.

Goaf—An excavated space, also the waste rock packed in old workings.

Goaves—Old workings.

Gob—See *Goaf*.

Gopher or Gopher-drift—An irregular prospecting drift, following or seeking the ore without regard to maintenance of a regular grade or section.

Gossan or Gozzan—Hydrated oxide of iron, usually found at the decomposed outcrop of a mineral vein.

Gouge—A layer of soft material along the wall of an ore deposit, favoring the miner, by enabling him, after "gouging" it out with a pick, to attack the vein from the side.

Grapnel—An implement for removing the core left by an annular drill in a bore-hole, or for recovering tools, fragments, etc., fallen into the hole.

Grampus—The tongs with which bloomy *lumps* and billets are handled.

Granite—A homogeneous crystalline granular mixture of feldspar (usually orthoclase) quartz and mica, showing no foliation or tendency to break in one direction more than in another. It may still be called granite when the per cent. of mica is very small. Granites may have been of eruptive origin, but their constituents show they were, in that case, produced by a secondary fusion of sedimentary rock. They often contain triclinic feldspars, and also hornblende.

Granite Family—The group of crystalline, homogeneous or non-foliated rocks, resembling granite, such as syenite, quartz-syenite, granityte, and all varieties of granite itself.

Granitelle—Binary granite, composed of feldspar and quartz.

Granityte—A mixture of orthoclase and oligoclase with a little quartz and mica.

Granitoid Rocks—The granite family includes rocks which have a general resemblance to granite, such as syenite, quartz-syenite, granulyte, granityte, granitelle, massive gneiss, etc.

Granulyte—A crystalline rock composed of orthoclase and quartz with garnet and kyanite (a silicate of alumina) as accessory minerals. Granulyte may be of eruptive origin notwithstanding its sometimes schistose character.

Graphic Granite—A variety of binary granite in which the quartz is disposed in the feldspar in such a way that in cross section it has some resemblance to Hebrew and Arabic writing, and from this circumstance it derives its name.

Graphite—Called also black lead and plumbago, because it can be used for marking like lead, although this metal does not enter into its composition. It consists of pure carbon, with a slight admixture of iron.

Grass-roots—A miner's term equivalent to the surface.

Grating—The plate of perforated metal or sieve fixed in the openings in mortar or stamper boxes in gold or silver crushing mills.

Greenstone—A general name for the compact granular trap rocks, such as diorYTE, diabase, basalt, etc., and is a convenient term for use in the field, where it is difficult to distinguish these rocks from one another. Trap has too wide a range of meaning.

Greywacke—A gray, ashy looking rock, consisting of a mixture of grains of feldspar and quartz with some amorphous mineral, and often containing rounded and angular fragments of all sizes, from that of peas up to boulders of a quartz-feldspar rock. These are often so abundant as to constitute a breccia-conglomerate. Greywackes are very common rocks in the Keewatin system in the vicinity of Vermilion lake.

Grit—Sandstone in which the grains are sharper or more angular than usual.

Grovan—Decomposed granite; sometimes the granite rock.

Groove or Grove (from *Grube*)—A mine.

Grundy—Granulated pig iron.

Gubbin—A kind of iron-stone.

Guides—The timbers at the sides of the shaft to steady and direct the cage.

Guillotine—A machine for breaking iron with a falling weight.

Gully—A small valley with steep sides, usually cut out of clay or earth.

Gunnies or Gunniss—The vacant spaces left where the lode has been removed.

Gypsum—Sulphate of lime, usually white and crystalline granular. Selenite is the pure crystalline form, and splits into plates which are very transparent. It is very soft, and is the mineral which constitutes the second degree of hardness, talc being the first. Gypsum occurs in beds in the Jura-Trias. Selenite crystals are found in the drift throughout western Minnesota.

Hack—1. See *Pick*. 2. A sharp blade on a long handle, used for cutting billets in two.

Hade—See *Underlay*.

Hair plate—See *Bloomary*.

Hanging-side, or *Hanging-wall* or *Hanger*—The wall or side above the ore-body.

Hardness of minerals—Mineralogists have adopted a conventional scale of hardness for minerals. It is divided into ten degrees, and the following minerals are used for reference as standards: 1 Talc, 2 Gypsum, 3 Calc spar, 4 Fluor spar, 5 Apatite, 6 Orthoclase feldspar, 7 Quartz, 8 Topaz, 9 Corundum, 10 Diamond. There is no scale of hardness for rocks, which are generally composed of mixtures of different minerals, but some varieties may be referred approximately to the scale for minerals.

Head-gear—That part of deep-boring apparatus which remains at the surface.

Heading—1. The vein above a drift. 2. An interior level or air-way driven in a mine. 3. In long-wall workings, a narrow passage driven up in a gangway in starting a working in order to give a loose end.

Head-piece—See *Cap*.

Headway—See *Cross heading*. The *headways* are the second set of excavations in post and stall work.

Heap—The refuse at the mouth of the pit.

Hearth—1. The floor or sole of a reverberatory. 2. The crucible of a blast furnace.

Heat—One operation in a heating furnace, Bessemer converter, puddling furnace, or other furnace not operating continuously.

Heating-furnace—The furnace in which blooms or piles are heated before hammering or rolling.

Heave—A miner's term for an upthrow. See *Dislocation*.

Heavyspar—Barytes or sulphate of barium. Celestite or sulphate of strontium is also a heavyspar easily mistaken for barytes. The carbonate of barium is witherite; that of strontium is strontianite.

Height-of-Land—See *Water Shed*.

Helve—A lift-hammer for forging blooms.

Hematite or *Hematite*—One of the commonest ores of iron. It is the peroxide or sesquioxide, and when pure contains about 70 per cent. of metallic iron and 30 of oxygen. It may be readily distinguished from magnetic and titaniferous iron ore by its red streak and powder, the others giving a black streak. Hematite is sometimes mixed with sufficient magnetite to cause it to adhere to the magnet. The hydrated variety of this ore is called limonite or brown hematite, the anhydrous being often distinguished as red hematite. It contains about 14 per cent. of water and gives a brown or yellowish streak. It is not always compact—yellow ochre, bog iron ore, umber, terra sienna, etc., being varieties of it.

Hercules powder—See *Explosives*.

Hexagonal—Having six angles, and consequently six sides. Crystals of quartz, apatite etc., are examples.

Hitch—1. Minor dislocation of a vein or stratum not exceeding in extent the thickness of the vein or stratum. 2. A hole cut in the side rock, when this is solid enough, to hold a cap set with timbers, permitting the leg to be dispensed with.

High explosive—An explosive or detonating compound developing more intense and instantaneous force than gunpowder. Most high explosives in general use contain nitro-glycerine. See *Explosives*.

Hog-back—1. A sharp anticlinal, decreasing in height at both ends until it runs out.

2. A ridge produced by highly tilted strata.

Hollow-fire—A kind of hearth with blast, used for reheating the stamps produced in the South Welsh process of firing, or the bars of blister-steel, in the manufacture of shear steel.

Homogeneous metal—A variety of ingot-metal produced by the open hearth process. See *Steel*.

Hopper—1. A trap at the foot of a shoot for regulating the discharge. 2. A place of deposit for ore.

- Horizon**—In geology, refers to the age or place of rocks in the chronological scale. A rock is spoken of as belonging to a higher or lower horizon according as it is newer or older than some other rock.
- Hornblende**—A very common mineral; so called from its hornlike cleavage and its lustre; also known as amphibole and amphibolite by the French. Usually dark green and blackish, but occasionally of light colors. It enters largely into the composition of diorite, rendering this rock very tough. It is also a constituent of syenite, some gneisses, etc. It is a silicate of magnesia, iron and lime, and its chemical composition differs but little from that of pyroxene or augite, this mineral being distinguished from it by crystalline form, etc. The principal varieties of hornblende are tremolite, actinolite and true asbestos.
- Hornstone**—The cherty and chalcedonic varieties of quartz.
- Horse**—A mass of country rock enclosed in a vein and almost or entirely surrounded by the vein stuff; sometimes called boulders. See *Salamander*.
- Hot-bed**—A platform in a rolling-mill on which rolled bars lie to cool.
- Hot-blast**—Air forced into a furnace after having been heated.
- Hudge**—An iron bucket for hoisting ore.
- Hummocky**—Lumpy, or in small uneven knolls.
- Huronian System**—The great system of primordial or sub-crystalline rocks belonging between the Keewatin (below) and the Cambrian or Lower Silurian system (above). This name was first given by Sir William Logan and Dr. T. Sterry Hunt to these rocks as they were largely developed on the north side of lake Huron, but the term has been pretty generally extended downward to include all the stratified crystalline rocks to the Laurentian. It is a synonym for Taconic.
- Hutch**—A low car suited both for running in a level and hoisting in a cage.
- Hydrated**—Containing water in chemical combination, and hence in a definite proportion in each case, as gypsum which contains "water of crystallization," hydrate of lime, or lime which has absorbed water on slacking, hydrated oxide of iron, or yellow ochre, which can be readily converted into the anhydrous or red oxide by driving off the water by heat.
- Hydraulic Cement**—Cement which sets under water. The rocks which, on being calcined and ground very fine yield this cement must contain, in addition to lime, certain proportions of alumina, silica and magnesia. A little iron is also usually present.
- Hydraulic Mining**—Washing down gold-bearing earth by means of a large and powerful jet of water brought from a considerable height and directed by a hose-pipe so as to have a pressure of from 50 to 100 pounds to the square inch. This process has been extensively used in California and has also been tried in the Chaudiere gold region of the Province of Quebec.
- Hydro-carbons**—Substances composed of hydrogen and carbon, as bitumens, paraffine, petroleum, benzine, etc.
- Hypogene**—A term proposed by Lyell for all nether-formed rocks, *i. e.* rocks which have assumed their present form at great depths beneath the surface, whether originally stratified or unstratified. The former belong to the metamorphic and the latter to the plutonic group.
- Iceland-spar**—The transparent variety of calcspar, found in perfection in Iceland. It possesses the property of double-refraction of light. If a dark line be viewed through it, it will appear as two parallel lines.
- Igneous**—Connected with subterranean heat. Igneous rocks are those which have evidently been once in a molten condition. Those which have cooled at or near the surface, such as lava and amygdaloid are called volcanic rocks; while those which have cooled at depths and under great pressure, such as granite, syenite, diorite, etc., are called plutonic rocks.
- Ilmenite**—Titanic iron or menacanite; a black heavy mineral like magnetite and composed of black oxide of iron with a varying quantity of oxide of titanium. It occurs similarly to magnetite. The black iron ores associated with the plagioclase or triclinic feldspar rocks appear to be prone to contain titanium. No profitable process has yet been discovered for the extraction of iron from ores containing more than a very small percentage of titanium.
- Impervious**—Impassable; applied to strata such as clays, shales, etc., which will not permit of the penetration of water, petroleum or natural gas.
- Impregnation**—An ore-deposit consisting of the country-rock impregnated with ore, usually without definite boundaries.
- Incline**—1. A shaft not vertical; usually on the dip of a vein. See *Slope*. 2. A plane, not necessarily underground.
- Indicator**—An instrument for showing at any time the position of the cage in the shaft.
- Indurated**—Hardened; applied to rocks hardened by heat, pressure, or the addition of some ingredient not commonly contained in the rock referred to, as marl indurated by carbonate of lime.
- Infiltration**—The deposition of matter among the grains or pores of a rock by the permeation or percolation of water carrying it in solution.
- Infiltration theory**—The theory that a vein was filled by the infiltration of mineral solutions.
- Ingot**—A cast bar or block of metal.
- Injection theory**—The theory that a vein was filled first with molten mineral.
- Inorganic**—Not organic; unconnected with animal or plant structure.
- In place**—Of rock, occupying, relative to surrounding masses, the position that it had when formed.
- In situ**—In position or place; applied to solid or fixed rocks as opposed to those which are loose and may have been transported.
- Inspissated**—Thickened as by evaporation and oxidation, as for example the pitch or gum resulting from petroleum after long exposure.
- Intake**—The passage by which the ventilating current enters a mine. See *Downcast*, which is more appropriate for a shaft; *Intake* for an adit.

Intercalated—In geology means interposed or placed between, as beds of one kind placed between or interstratified with those of another kind.

Interstratified—Or interbedded. Strata laid between or alternating with others.

Intrusive—Applied to igneous rocks which have been forced between or into the midst of others.

Iridescent—Colored like the rainbow. A play of colors such as is seen on the peacock's tail. Labradorite and some other feldspars show it. The tarnish on the surface of coal, copper pyrites, etc., is sometimes iridescent.

Iron—The principal varieties of iron are *wrought-iron* and *cast-iron* (see *Pig-iron*). *Wrought-iron*, also called *bar-iron* and *weld-iron*, is the product of the forge or the puddling furnace; *cast-iron* of the blast furnace. The former approaches pure iron; the latter is an alloy of iron and carbon. Steel, except some of the so-called "low" or "mild" steels, which are more nearly wrought-iron (fused and cast), stands between them, having less carbon than cast-iron and more than wrought-iron. Some of the carbon in cast-iron is usually segregated during cooling, in the form of graphite, and this determines the grade of the iron as *No 1 foundry* (the most graphitic, coarsely crystalline, soft and black), *No 2 foundry* (less open in grain), *gray forge or mill iron* (still closer in grain, suitable for puddling), *mottled*, (spotted with *white-iron*), and *white* (hard, brittle, readily crystalline containing its carbon mostly in alloy with the iron, and showing no visible graphite). These grades are called simply *No. 1, 2, 3*, etc. So-called *silver gray*, *glazy* or *carbonized iron* is usually an iron rendered brittle by excess of silicon. *Ingot iron*, see *steel*. *Anthracite*, *charcoal* and *coke iron*, are names given to pig-iron according to the fuel with which it is made.

Iron hat—See *Gossan*.

Iron-ores—*Magnetic* (*Magnetite* protoperoxide) *specular* (*hematite* proper) *red hematite* (anhydrous peroxide), *brown iron ore*, *hematite*, *brown hematite*, *limonite*, etc., (hydrated peroxides), *spathic* (*siderite*, *carbonate*), *clay ironstone* (*black band*, *argillaceous siderite*).

Iron Pyrites—Or simply pyrite; bi-sulphide of iron. A hard, heavy, shiny, yellow mineral, generally in crystals of the cubic system. It may be distinguished from copper pyrite by being of a paler yellow color, harder and giving a black powder, whereas copper pyrites gives a yellow powder. When struck by steel, or when two pieces are struck briskly together sparks of fire are emitted, accompanied by the odor of sulphur. A very common mineral. *Marcasite* has the same composition, but is white and crystallizes differently. *Pyrrhotite* or *magnetic pyrites* is the monosulphide of iron and is of an iron-gray to bronze color.

Ironstone—Any ore of iron from which the metal may be smelted commercially, but usually restricted to stratified ores, especially to clay-ironstone - the ore from which most of the iron of Great Britain and Pennsylvania has been made.

Isochemic lines—Planes or lines of equal content of phosphorus in any single layer of iron ore.

Isoclinal—Applied to strata which have been so completely overturned that the upper fold or inverted portion dips in the same direction as the corresponding lower portion.

Jars—A part of percussion-drilling apparatus for deep holes, which is placed between the *bit* and the *rods or cable*, and which by producing at each up-stroke a decided jar of the *bit* jerks it up though it may be tightly wedged in the hole.

Jasper—Compact opaque varieties of quartz with conchoidal fracture and usually capable of a high polish. The colors are red, brown, green spotted, nearly white, etc. When it carries hematite in the Keewatin it has been named *jaspilite*.

Jig-Chain—A chain hooked to the back of a *skip* and running around a post, to prevent too rapid descent on an inclined plane.

Jigging—One of the operations in the dressing of crushed ores, such as those of lead, copper, etc. The usual process consists in shaking or jerking the ore in a wire-bottomed sieve suspended in a vat of water. This allows the fines to pass through and they are afterwards treated in buddles, while the rest becomes sorted according to its relative gravity. The waste fragments are scraped off the top, the process being called *skimping*.

Joints—The nearly vertical division-planes which traverse nearly all rocks. They are called backs by quarrymen.

Jump—1. To take possession of a mining or other claim alleged to have been forfeited or abandoned. 2. A fault or dislocation of a bed or vein.

Juniper—A short steel drill for boring holes in rock for blasting or for splitting by gads.

Jurassic System—The system which succeeds the Triassic; so called after the Jura mountains on the border between Switzerland and France. It corresponds with the *Oolite* of England.

Kames—Ridges of sand and gravel of which the stratification is rudely parallel to the slopes of the surface. Their origin has not been satisfactorily accounted for.

Kaolin—Clay, usually very light in color, derived from the decomposition of the silicates of the crystalline rocks. It is used for the manufacture of porcelain.

Kawishwatin—The iron-bearing belt of the Keewatin. The greenstone, or dioritic, (upper) part of the Keewatin.

Keewatin—From the Chippewa, meaning *Northeast*. Applied by A. C. Lawson to the semi-crystalline schists that immediately follow the crystalline schists. They consist of silky mica schists, gray wackes and chloritic schists, with agglomerates and tuffs; the whole being largely of volcanic origin. Contains the iron ore at Tower and Ely.

Kibball or Kibble—An iron bucket for raising ore.

Kies—The pure or separated sulphides, as distinguished from the vein-matter in bulk.

Kiln—A large receptacle for calcining ores, limestone, etc.

Kindly—A miner's term for a rock which is considered congenial or likely for carrying ore.

- Kish**--The blast-furnacemen's name for the graphite segregations seen in pig-iron and in the cinder of a furnace, making a very gray iron.
- Knobbing-fire**--A *bloomary* for refining cast-iron.
- Krupp washing process**--The removal of silicon and phosphorus from molten pig-iron by running it into a *Pernot furnace*, lined with iron oxides. Iron ore may also be added, and the bath is agitated by rotation for five to eight minutes only.
- Labradorite**--Lime soda feldspar; a silicate of alumina, lime and soda. Crystallization, triclinic. See *Feldspar*.
- Labor**--Labor; work; a working. This term is applied in mining to the work which is actually going on, and to the spaces which have been dug out. It includes galleries, cavities and shafts.
- Laboratory**--1. A place fitted up for chemical analyses, etc. 2. The space between the fire and flue bridges of a *reverberatory furnace* in which the work is performed; also called the *kitchen* and the *hearth*.
- Laccolite**--A mass of igneous rock which has not reached the surface, but has been forced between two beds of rock where it has spread out. The typical examples occur in the Henry mountains.
- Lacustrine deposits**--Deposits formed in the bottom of lakes.
- Lagging**--Planks, slabs or small timber placed over the caps or behind the posts of the timbering, not to carry the main weight, but to form a ceiling or a wall, to prevent fragments of rock from falling through.
- Lander**--The man at the shaft-mouth who receives the *kibble*.
- Land-slides or slips**--Large masses of clay, earth or rock which have lost their support and slid down, sometimes temporarily blocking up streams or railroads.
- Launder**--A spout or trough for carrying water for a short distance.
- Laurentian System**--The lowest rocks of the Archæan, principally acidlic gneisses and granites.
- Lateral**--Belonging to the sides, or to one side.
- Lead**--An auriferous deposit following the former bed of a stream now covered by superficial deposits. In general use quartz veins are called leads.
- Leader**--A small ore shoot leading to larger bodies.
- Lean**--Applied to poor ores or those containing a lower percentage of metal than is usually worked.
- Leap**--A fault. See *Jump*.
- Lenticular**--Shaped approximately like a double convex lens. When a mass of rock thins out from the centre to a thin edge all round it is said to be lenticular in form.
- Lentille**--An isolated mass of rock containing fossils of a fauna older than the strata in which it occurs, though of cotemporary age with those strata.
- Level**--A horizontal passage or drift into or in a mine. It is customary to work mines by levels at regular intervals in depth numbered in their order below the surface or below the *adit* if there be one.
- Leg**--A prop of timber supporting the end of a *stull*, or the *cap* of a set of timber.
- Lignite**--See *Coal*.
- Limestone**--A rock composed of carbonate of lime; of all colors and varieties in texture from compact or amorphous to coarsely crystalline. White marble is a finely crystalline variety. Chalk is a soft form. Limestone may be distinguished from other rocks by being easily scratched with a knife and by effervescing when acid is placed upon it.
- Limonite**--Brown hematite; hydrated oxide of iron. See *Hematite*.
- Lithology or Petrology**--The study of rocks as such; a branch of geology which is being much developed in recent years. By making thin sections and examining them under the microscope the nature of a rock may be determined as well for most purposes as by chemical analysis.
- Loam**--A mixture of sand and clay. If decayed vegetable matter be added, it assumes a dark color and is called vegetable loam.
- Location**--1. The act of fixing the boundaries of a mining claim according to law. 2. The claim itself.
- Loch**--See *Vug*.
- Lode**--Strictly a fissure in the country-rock filled with mineral; usually applied to metalliferous lodes. In general miner's usage, a *lode*, *vein* or *ledge* is a tabular deposit of valuable mineral between definite boundaries. Whether it is a fissure formation or not is not always known, and does not affect the legal title under the United States federal and local statutes and customs relative to lodes.
- Loess**--A peculiar deposit like fine silt found in some parts of northern Europe, northern China and in the north-western United States.
- Long-Ton**--A trough for washing gold-bearing gravel or earth.
- Long-wall**--A method of mining coal and iron ore by which a whole seam or bed is taken out as the working faces progress, and the roof is allowed to fall in behind the workers, except where passages must be kept open, or where the *gob* being packed in the space formerly occupied by the coal or ore, prevents caving. According as the work of extraction begins at the boundary of the *winning*, and converges back to the shaft, or begins nearest the shaft and extends outward to the boundaries of the property, it is called *long-wall retreating* or *long-wall advancing*.
- Loop**--See *Loup*.
- Loop-drag**--An eye at the end of a rod through which tow is passed for cleaning bore-holes.
- Lorry**--A hand-car used on mine tramways.
- Lost level**--"Level" is "lost" when a gallery has been driven with an unnecessarily great departure from the horizontal.
- Loup**--The pasty mass of iron produced in *bloomary* or *puddling* furnace. See *Puddle-ball*.

Lowe—A light. A "piece of lowe" is part of a candle.

Lum—A chimney over an upcast pipe.

Lurman front—An arrangement of water-cooled castings through which iron and cinder are tapped from the blast furnace, thus avoiding the use of forehearth.

Lying-wall—See *Foot-wall*.

Lustre—The character of the light reflected by minerals; it constitutes one of the means of distinguishing them.

Lydian-stone—A compact or close grained, nearly black, variety of jasper. A smoothed surface of this stone is used for trying the streak of gold, the color of which affords an index to its purity.

Macroscopic—Readily seen by the naked eye. On a large scale compared with microscopic; same as megascopic.

Magnesian Limestone—See *Dolomite*.

Magnetic Iron Pyrites—See *Iron Pyrites*.

Magnetite—Or magnetic iron ore. Black oxide of iron. In addition to its magnetism it may be distinguished from hematite by yielding a black streak and powder.

Mainway—A gangway or principal passage.

Malleable castings—Small iron castings made malleable by "annealing" or decarburizing by cementation in powdered hematite or other oxide of iron.

Mallet—The sledge-hammer used for striking or beating the borer.

Maltha—The pitch or "gum" resulting from the drying up and oxidation of petroleum, as when it has reached the surface of the ground.

Mammillated—Having the form of paps or breasts.

Mammoth—A fossil elephant allied to the living species, but larger.

Manganese—A metal chemically related to iron. The black oxide, pyrolusite, the gray oxide, manganite and the earthy oxide, wad, are used in the arts. Manganese is used in the manufacture of Bessemer steel.

Man-hole—The hole in a *sollar* through which men pass upon the ladder or from one ladder to the next.

Mantle—The outer wall and casing of an iron blast furnace, above the hearth.

Manway—A small passage, used by workmen, but not for transportation.

Marble—A variety of moderately soft rocks capable of taking a good polish is called marble. The commonest are compact and crystalline limestones and dolomites and serpentine.

Marcasite—See *Iron Pyrites*.

Marl—Usually applied to a soft or friable natural mixture of clay and lime.

Marly—Resembling marl.

Martin process—Called also the *Siemens-Martin* and the *open hearth* process. See *Steel*.

Massive Rocks—Those which have no stratification or lamination, as greenstones, granite, syenite, etc.

Mastodon—A genus of extinct elephantine mammals, having conical protrusions on the grinding surfaces of their teeth, whereas the mammoth has flattened transverse ridges.

Matrix—The rock or earthy material containing a mineral or metallic ore; the *gangue*.

Matt or Matte—A mass consisting chiefly of metallic sulphides obtained in the fusion of ores.

Maul—A large hammer or mallet.

Measures—A general name for stratified rocks.

Megascopic—Visible to the unaided eye. Macroscopic.

Merchant-train—A train of rolls for reducing iron *piles* or steel *ingots*, *blooms* or *billets* to bars of the various round, square, flat or other shapes, known as merchant iron or steel.

Mesozoite—Or secondary; the "middle-life" period or age. It is the third of the five grand divisions of geological time. It includes (in ascending order), the Triassic, Jurassic and Cretaceous systems.

Metal—This term is applied by miners both to the ore and to the metal extracted from it. It is sometimes used for vein, and even for a mine itself. It includes all the rocks met with in mining ores. *Road metal* is rock used in macadamizing roads.

Metalliferous—Carrying metal.

Metal-notch—See *Tap-hole*.

Metamorphic—Applied to the rocks which have been changed in form and internal structure. Heat, pressure and time acting on the constituents of rocks have been the main causes of metamorphism, converting ordinary and soft sedimentary deposits into crystalline and hard rocks.

Metamorphism—The change in form, etc., which some rocks have undergone, or the process itself. Alteration has a different meaning, but is sometimes used synonymously.

Meteorite—See *Aerolite*.

Mica—A common mineral easily recognized by its glistening appearance and from the fact that it may be split into very thin leaves which are flexible. It enters into the composition of mica-schist, gneiss, granite and other crystalline rocks, and is found in scales in sands and sandstones derived from their disintegration. Ignorant persons sometimes speak of it improperly as isinglass, which is made from the swimming bladder of the sturgeon.

Micaceous—Containing mica or largely composed of it.

Mica-schist—A foliated crystalline rock composed of alternate layers of quartz and mica in various proportions, the typical one being about two-thirds quartz to one-third mica; although the proportion of the latter generally appears greater than it is, because the rock splits along the mica folia, thus showing the mica alone on the flat surfaces. The true composition may be seen by looking at the squarely broken edges. Orthoclase is a common constituent.

Microscopic—So small as to be seen only by the microscope.

- Mill**—1. That part of an iron works where *puddle-bars* are converted into *merchant iron*, *i. e.*, rolled iron ready for sale in bars, rods or sheets. 2. By common usage any establishment for reducing ores by other means than smelting; more strictly, a place or a machine in which ore or rock is crushed. 3. An excavation made in the *country rock* by a *cross-cut* from the workings on a vein, to obtain waste for *gobbing*. It is left without timber so that the roof may fall in and furnish the required rock. 4. A passage through which ore is shot underground.
- Millstone Grit**—In Great Britain this name is given to a part of the Carboniferous system consisting principally of sandstones, below the Coal Measures; it is also sometimes used for the equivalent group in America.
- Mine**—In general, any excavation for minerals or ores. More strictly, subterranean workings, as distinguished from *quarries*, *placer* and *hydraulic* mines, and surface or open works.
- Mineral**—Scientifically, any inorganic substance having a definite chemical composition and crystallizing in definite forms. Each of these constitutes a mineral species. See *Rock*. But the word means literally anything dug out of the earth, and in this sense includes everything except living or recently dead organic matter. Many mineral substances, such as coal, some limestones, etc., are composed of mineralized organic matter.
- Mineralization**—The conversion of a substance into mineral, as peat into coal.
- Mineralogy**—The study or science of minerals; often confounded with geology, which see.
- Miocene**—The middle Tertiary system.
- Molecule**—An ultimate particle of matter, having a definite chemical composition.
- Mollusca**—One of the primary divisions or provinces of the animal kingdom; it embraces those soft-bodied invertebrates most but not all of which are provided with shells, as oysters, snails, slugs, etc.
- Molybdenite**—Sulphide of molybdenum—a soft bluish black, usually laminated mineral occurring in veins of quartz, etc., having somewhat the appearance of graphite, but in most cases yielding a dark green mark on white paper. If found in considerable quantity it has a commercial value.
- Monkey-drift**—A small prospecting drift.
- Monoclinical**—Applied to any limited portion of the earth's crust throughout which the strata dip in the same direction.
- Moon-stones**—Pale, opalescent, almost transparent varieties of feldspars.
- Moraines**—Piles or ridges of boulder-drift or till which have accumulated at the sides (lateral) or lower extremities (terminal) of glaciers.
- Mortar Box**—The large deep cast-iron box into which the stamps fall and the ore is fed in a gold or silver stamp mill; also called a *stamper-box*.
- Moss Agate**—A variety of agate showing branching forms like those of moss.
- Mountain Cork**—An extremely light non-fibrous variety of asbestos.
- Muck-bar**—Bar-iron which has passed once through the rolls.
- Mullock**—A term sometimes used for the accumulated waste or refuse rock about a mine.
- Mundic**—Iron pyrites. White *mundic* is *mispickel*.
- Naphtha**—A highly volatile liquid form of hydro-carbon.
- Narrow work**—The driving of *gangways* or *airways*; also any *dead work*.
- Native**—Occurring in nature; not artificially formed. Usually applied to pure metals, uncombined.
- Neutral**—Of slags, neither acid nor basic; of wrought-iron, neither *red short* nor *cold short*; of iron ores, suitable for the production of neutral iron.
- New Red Sandstone**—The former name for the Permian system; it lies above the Carboniferous, while the Old Red Sandstone lies below it.
- Nickel**—One of the metallic elements. It is a white metal, having a lustre like silver, but in its chemical relations it is more nearly connected with iron; it is not, however, susceptible to oxidize like iron, and this is one of the properties which renders it so valuable for plating this metal. It has recently been found to give great toughness to steel, a most valuable property. Nickel is found most abundantly as a sulphide, associated with iron and copper.
- Noble Metals**—The metals which have so little affinity for oxygen (*i. e.*, are so highly electronegative) that their oxides are reduced by the mere application of heat without a reagent; in other words, the metals least liable to oxidation under ordinary conditions. The list includes gold, silver, mercury and the platinum group, palladium, iridium, rhodium, ruthenium and osmium.
- Nodule**—A concretion in a soft matrix, as the kidney stones found in clays almost everywhere. The bombs or kettles in the black shales of the Kaministiquia and Whitefish valleys are only great nodules. The flints of the chalk of England and the detached lumps of clay iron-stone of the Carboniferous shales, etc., are other forms of nodules. Nodules have generally formed themselves around some fragment of either organic or inorganic matter as a centre or nucleus. Similar nodules are found in the Animike slates at Thomson, Minn., and on the Vermillion river northwest of Sudbury.
- Nose**—An accumulation of chilled material around the inner end of a *tuyere* in a smelting shaft furnace, protecting and prolonging the *tuyere*.
- Nugget**—A lump of native gold, silver, platinum, copper, etc.
- Obsidian**—Dark-colored volcanic glass, the product of volcanoes of later geological times. It is a silicate of alumina, potash, soda and lime.
- Ochre**—Naturally occurring pigments, as yellow ochre or hydrated oxide of iron. Blue, green, red, etc., clayey mixtures which may be used as coarse paints are also called ochres. Ochre is also used as a mineralogical term for certain decomposition oxides, as bismuth, chrome, antimony and cobalt-ochres.
- Old Nan**—Ancient workings, *goaves*.
- Old Red Sandstone**—See *New Red Sandstone*.
- Oligoclase**—Soda-lime feldspar; a silicate of alumina, soda and lime. Crystallization, triclinic. See *feldspar*.

- Olivine*—An earthy looking olive-green mineral, occurring in many trappean rocks.
- Oolite*—A limestone composed of small round grains, resembling fishes' eggs, hence the name.
- Opal*—A gem composed of silica, with from 5 to 10 per cent. of water, having a "play of colors," or reflecting rainbow-like colors, with a brilliance or "fire" that gives to sound pieces a great value. Generally white and having a hazy or milky translucency.
- Opalescent*—Resembling opal.
- Open Crib Timbering*—Shaft timbering with *cribs* alone, placed at intervals.
- Open Cut, Open Pit*—A surface working, open to daylight.
- Open Front*—The arrangement of a blast-furnace with a *fore-hearth*.
- Opens*—Large caverns.
- Open Work*—A quarry or open cut.
- Ore*—Properly speaking, combinations of metals with other substances, but also applied to the matrix from which native metals, such as gold, silver and copper are extracted. Sometimes, also, applied to other minerals won by mining, as apatite, barytes, etc.
- Ore-Washer*—A machine for washing clay and earths out of earthy brown-hematite ores.
- Organic*—Having organs for carrying on vital processes. Animals and plants are thus organized as distinguished from minerals or inorganic substances. When these organs or organic structures become mineralized they are fossils, or organic remains.
- Orthoclase*—Potash feldspar; a silicate of alumina and potash. Crystallization, monoclinic. See *feldspar*.
- Outcrop*—The portion of a vein or stratum appearing at the surface, or immediately under the soil and surface debris.
- Outlet*—The passage by which the ventilating current goes out of a mine. See *upcast*.
- Outlier*—A portion detached from the main body, an island, as it were, surrounded by some other kind of rock.
- Output*—The product of a mine.
- Overlap*—When strata extend over an ancient formation further than those immediately preceding them, this extension is called an overlap.
- Overturned*—Where strata have been highly tilted till they pass the perpendicular, so that the lower fold becomes turned upside down, they are said to be overturned.
- Oxidation*—A chemical union with oxygen.
- Oxide*—A compound of the element oxygen with another element or other elements.
- Pack*—A wall or pillar built of *gob* to support the roof.
- Pair or Pare*—Two or more miners working in common.
- Palaeontology*—The science of ancient life, especially of animal remains, that of plant remains or fossil botany being called palaeobotany.
- Palaeozoic*—The second of the five grand divisions, periods, or ages of the rocks of the earth's crust; so called from containing evidences of the most ancient life on the planet. The Palaeozoic period includes (in ascending order) the Taconic, Cambrian, Silurian, Devonian, Carboniferous and Permian systems.
- Pane*—The striking face of a hammer.
- Panel*—A heap of dressed ore.
- Parachute*—1. A kind of *safety-catch* for shaft cages. 2. In rod-boring a *cage* with a leather cover to prevent a too rapid fall in case of accident.
- Paroxysm*—In geology, any violent or sudden natural occurrence, as a volcanic eruption, a sudden flood, etc.
- Parting*—A thin layer separating greater masses of rock, usually beds, as a parting of shale between beds of sandstone or limestone.
- Parting Sand*—Fine, dry sand, which is sifted over the partings in a mould to facilitate their separation when the flask is opened.
- Pass*—1. An opening in a mine through which ore is shot from a higher to a lower level. See *Shoot*. 2. In rolling mills the passage of the bar between the *rolls*. When the bar passes "on the flat" it is called a "*flating-pass*"; if "on the edge," an "*edging pass*."
- Patchy*—Distributed in patches or in an irregular manner as when ore occurs in bunches or sporadically.
- Pavement*—The floor of a mine.
- Peat*—A mass of vegetable matter formed in bogs and marshes. Its principal constituent is sphagnum moss, but rushes, reeds, sedges, grasses, algae, etc., may also contribute. Peat sometimes accumulates to considerable depth; the lower portion becomes black and dense and is used for fuel. The rotten wood found in the bottoms of *swamps* is not peat, properly speaking.
- Pegmatite*—A very coarse variety of granite, composed principally of quartz and crystalline feldspar, but often holding sheets of mica. It usually forms great veins or enlargements of veins cutting mica-schist, gneiss, etc. Formerly applied also to finer mixtures of quartz and feldspar, called binary granite, now known as granulyte and quartz-feldspar rock.
- Permian System*—The system next above the Carboniferous; formerly called the New Red Sandstone; the Devonian or next system below the Carboniferous being the Old Red Sandstone. This name (introduced in 1841 by Sir Roderick Murchison) is derived from the government of Perm in Central Russia, where the system is well developed. There, as in the north of England, it is made up principally of red sandstones.
- Pernot furnace or Post-Pernot furnace*—A *reverberatory* puddling or smelting furnace, having a circular, inclined, revolving hearth.
- Peter or peter out*—To fail gradually in size, quantity or quality.
- Petrify*—To become stone. Organic substances, such as shells, bones, wood, etc., embedded in sediments, become converted into stone by the gradual replacement of their tissues, particle by particle, with corresponding amounts of infiltrated mineral matter. Thus not only the outward forms but even the minutest details of the organic tissues are preserved.

- Petroleum**—Or rock-oil; liquid hydrocarbon. Formed in large quantities in some rocks which contain organic matter.
- Petrology**—See *Lithology*.
- Petrosilex**—A compact siliceous felsyte having a fracture like jasper distinguishable from it in being fusible before the blowpipe.
- Pick**—A pick-axe with one or two points.
- Pig**—An ingot or cast bar of metal.
- Pig-iron**—Crude cast iron from the blast furnace. When the furnace is tapped the molten iron flows down a *runner* moulded in sand, from which it enters the *sows* or lateral runners, flowing from these again into the *pig-beds*, the separate parallel moulds of which form the *pigs*. In each bed the ingots lie against the *sow* like suckling pigs, whence the two names. See *Iron*. *Mine-pig* is pig iron made from ores only; *cinder-pig*, from ores with admixture of some *forge* or *mill-cinder*.
- Pile**. 1. The fagot or bundle of flat pieces of iron prepared to be heated to welding heat and then rolled. 2. To make up into *piles* or *fagots*.
- Pillars**—Portions of the vein or bed left standing to support the roof.
- Pillar-and-stall**—See *Post-and-stall*.
- Pinched**—Where a vein narrows, as if the walls had been squeezed in. When the walls meet the vein is said to be pinched out.
- Pipe or pipe-vein**—An ore-body of elongated form.
- Pipe-ore**—Iron ore (limonite) in vertical pillars, sometimes of conical, sometimes of hour-glass form embedded in clay. Probably formed by the union of stalactites and stalagmites in caverns.
- Pit**—A shaft; an open mine or working.
- Pitch**—The inclination of a vein, or of the longer axis of an ore-body, different from *dip* or *strike*, but lying in the same plane.
- Pitch-bag**—A bag covered with pitch in which powder is enclosed for charging damp holes.
- Pitchstone**—A dark glassy or pitchy looking igneous rock, occurring as dykes, and also as beds which have flowed upon the former surface. It is a natural glass with splintery fracture, although translucent only on thin edges, and has the composition of felsyte.
- Placers**—Gold-bearing sand and gravel deposited on the bed-rock.
- Plagioclase**—The triclinic feldspars are called collectively plagioclase. The principal triclinic feldspars are albite, anorthite, labradorite and oligoclase. As constituents of rocks they occur generally in small crystalline grains, and without a microscopic examination it is difficult to distinguish them in this form from one another; hence this term is very convenient for use in the field.
- Plane**—An incline with tracks, upon which materials are raised in cars by means of a stationary engine or are lowered by gravity.
- Plank-timbering**—The lining of a shaft with rectangular plank frames.
- Plank-tubbing**—The lining of a shaft with planks, spiked on the inside of *curbs*.
- Plaster of Paris**—A plaster made from gypsum by grinding and calcining it; so called from its manufacture near Paris in France. In general this term has been adopted for gypsum in any form.
- Plastic Clay**—In England, applied to certain clays of the Eocene system, but in general means clay suitable for moulding into any form.
- Plat**—The map of a survey, in horizontal projection.
- Platt**—An enlargement of a level near a shaft, where ore may await hoisting, wagons pass each other, etc.
- Pleistocene System**—Or Post-Pliocene. The system which succeeds the Pliocene. It embraces the remains of a few extinct species of animals, especially of mammals, while those of the Recent belong entirely to species still living.
- Plicated**—Folded together, as in highly inclined and contorted strata.
- Pliocene System**—The uppermost of the Tertiary systems; divided into the Older Pliocene, in which from 35 to 50 per cent. of its embedded species are still living, and the Newer Pliocene, in which the proportion is from 90 to 95 per cent.
- Plug**—A hammer closely resembling the *bully*.
- Plumb**—1. Vertical. 2. Soft.
- Plumbaginous**—Containing plumbago, as plumbaginous schists; some crystalline limestones are also plumbaginous.
- Plumbago**—Graphite.
- Plunger**—The piston of a force pump.
- Plutonic Rocks**—Igneous rocks which have cooled at a considerable depth from the surface and under great pressure. See *Igneous*.
- Pocket**—1. A small body of ore. 2. A natural underground reservoir of water. 3. A receptacle from which coal, ore or waste is loaded into wagons or cars.
- Polings**—Poles used instead of planks for *lagging*.
- Poll-pick**—A pick with a head for knocking down rocks already seamed by blasting.
- Ponsard furnace**—A furnace in which the escaping combustion gases, passing through tubular flues, heat the incoming air continuously through the flue-walls.
- Poppet heads**—A timber frame over a shaft to carry the hoisting pulley.
- Porphyry**—Any massive rock with crystals distinct from the matrix. Typical porphyries are however those which have a feldspathic ground-mass or matrix with a compact or flinty texture and holding disseminated crystals of feldspar. Quartz-porphyry contains a considerable proportion of quartz in addition to the feldspar, and crystals of both minerals are scattered through it; but where no such crystals occur and the whole mass is compact, it forms a variety of felsyte. Porphyry was originally applied to a red syenite with distinct feldspar crystals from Upper Egypt, and all similar rocks are still included among the porphyries.
- Porphyritic**—Resembling porphyry.
- Post**—1. A pillar of coal or ore. 2. An upright timber.

- Post-and-stall**--A mode of working coal or iron ore in which so much is left as pillar and so much is taken away, forming *rooms* and *thirlings*. The method is called also *board-and-pillar*, *pillar-and-breast*, etc.
- Post Tertiary Period**--Also called Quaternary. The newest of the five grand divisions of geological times. It includes the Pleistocene or Post-Pliocene and the Recent or Prehistoric systems, which bring us up to the present or historic time.
- Pot-holes**--Kettles; circular holes sometimes much deeper than wide, worn into the solid rock at falls and strong rapids, by sand, gravel and stones being spun round by the force of the current.
- Potstone**--A coarse or impure variety of soapstone; so called from being easy to cut into pots owing to its softness.
- Power drill**--See *Rock-drill*.
- Precious metals**--See *Noble metals*.
- Precipitate**--When a substance, held in solution in a liquid, is thrown down in a solid form by the addition of some other substance in solution, the resulting solid is called a precipitate. When a substance held only mechanically in suspension in a liquid settles to the bottom it is called a sediment.
- Prill**--A good sized piece of pure ore.
- Primary**--See *Paleozoic*.
- Primitive**--See *Archean*.
- Primoval**--The name given by Barrande to the oldest fossiliferous rocks as developed in Bohemia. It corresponds with the American Taconic and the British lower Cambrian.
- Prop**--A timber set to carry a roof or other weight acting by compression in the direction of the axis.
- Prop-cut timbering**--Shaft-timbering with *cribs* kept at the proper distance apart by *props*.
- Prospecting**--Searching for new deposits; also preliminary explorations to test the value of lodes or ore-beds.
- Prospector**--A person engaged in exploring for valuable minerals, or in testing supposed discoveries of the same.
- Protogene**--A variety of granite in which chlorite or talc takes the place of mica; so called by the French, who supposed that it was the first-formed of the granites. The granites of Cornwall, England, which decompose and yield kaolin are of this kind.
- Pseudomorph**--False form; the name given to crystalline forms of a composition not proper to such forms. They may be mere casts, occupying cavities from which crystals have been dissolved, or they may have replaced other crystals particle by particle by some slow process.
- Pudding-stone**--A conglomerate in which the pebbles are rounded. See *Breccia*.
- Puddling**--1. The process of decarburizing cast iron fusion on the hearth of a reverberatory furnace, lined *lined* or *settled* with ore or other material rich in oxide of iron. The bath is stirred with a *rabbie* to expose it to the action of the lining and of an air current. The escape of carbonic acid causes it to boil, whence the early name of this method of puddling, viz., *boiling*. *Dry puddling* is performed on a siliceous hearth, and the conversion is effected rather by the flame than by the reaction of solid or fused materials. As the amount of carbon diminishes the mass becomes fusible and begins to coagulate (*come to nature*), after which it is worked together into lumps (*puddle-balls*, *lumps*) and removed from the furnace to be hammered (*shingled* or *squeezed* in the *squeezer*, which presses out the *cinder*, etc., and compacts the mass at welding heat, preparatory to rolling. Silicon and phosphorus are also largely removed by puddling, passing into the *cinder*. Mechanical *puddlers*, in which the bath is agitated by revolution or by mechanical *rabbies*, to save hand labor, are used to a limited extent. 2. The term *puddling*, now applied in metallurgy exclusively to the above process, originally referred to the *puddling* of clay or clay and charcoal upon the masonry of a furnace hearth to form a lining. Ditches, reservoirs, etc., are *puddled* with clay to make them water-tight.
- Pumice**--A very light, porous and vesicular lava which will float on water; a sort of volcanic froth. Its color is generally whitish or light gray.
- Pyrites**--See *Iron Pyrites*.
- Pyrolusite**--Black oxide of manganese; used for making oxygen.
- Pyro-schists**--Bituminous shales which yield hydrocarbon oils and gases on distillation.
- Pyroxene**--See *Augite*.
- Pyrrhotite**--See *Iron Pyrites*.
- Quartz**--A common mineral occurring in a great variety of forms. It is composed of the elements silicon and oxygen. It crystallizes in the hexagonal system. The transparent colorless variety, which is the purest form, is called *rock-crystal*. White or milk-quartz is a very common vein-stone. Gold occurs most frequently with quartz, but only a small proportion of quartz veins contain gold. The numerous varieties of quartz may be classified in three groups: (1) the vitreous, like *rock-crystal*, *rose quartz*, *amethystine quartz*, etc.; (2) the chalcodonic, like *chalcodony*, *carnelian*, *agate*, *flint*, etc.; (3) the jaspery, like *jasper*, *bloodstone*, *lydian stone*, etc.
- Quartzite**--Quartz rock; a rock composed of grains of quartz cemented, or, as it were, fused together by the same substance. Quartzites are indurated sandstones; they often contain grains of feldspar. Among the Huronian rocks, great belts of quartzite occur from lake Huron north and northwestward; also in central Wisconsin and southwestern Minnesota.
- Quartzose**--Containing quartz as a principal ingredient.
- Quaternary**--See *Post Tertiary*.
- Quere, Queere, Quear**--A small cavity or fissure.
- Quick**--Applied to a productive ore deposit, as against one that is *dead* or *barren*.

- Quick-lime**—When carbonate of lime (limestone) has been thoroughly calcined this results. By the addition of water it forms hydrate of lime, the process being called slaking.
- Quicksilver**—A common name for mercury; one of the metallic elements, remarkable for its low melting point, being liquid down to 40° Fah. below zero.
- Rabble**—An iron bar bent to a right angle at the end.
- Race**—An artificial canal for conveying water.
- Rail-train**—A train of rolls for reducing iron *piles* or steel *ingots* or *blooms* to rails.
- Rake**—A fissure vein crossing the strata.
- Random**—The direction of a *rake-vein*.
- Range**—A chain of mountains or hills; also a belt or strip of country within which certain economic minerals are supposed to occur or run.
- Rapper**—A lever or hammer at the top of a shaft or inclined plane, for signals from the bottom.
- Reamer**—A tool for enlarging a bore-hole.
- Recent**—The present geological time, although it extends back through a vast period of years. All or nearly all existing species of animals have lived throughout the Recent epoch.
- Red-short**—Brittle at red heat, caused by an excess of sulphur.
- Reduce**—1. To deprive of oxygen. 2. In general, to treat metallurgically for the production of metal.
- Reef**—In mining, often applied to quartz veins or veins of any kind; also to solid or fixed rock in general, as opposed to loose materials.
- Refractory**—Resisting the action of heat and chemical reagents; a quality undesirable in iron ores, but desirable in furnace linings, etc.
- Resin**—Mineral resin; substances allied in composition to the resins of coniferous trees, such as amber.
- Reticulated**—A net-like arrangement.
- Rests**—The arrangement at the top and bottom of a pit for supporting the shaft-cage while changing the tubs or cars.
- Reverberatory furnace**—A furnace in which ores are submitted to the action of flame, without contact with the fuel. The flame enters from the side or end, passes upward over a low wall or *bridge*, strikes the roof (*arch*) of the furnace, and is *reverberated* downward upon the charge.
- Rib**—The solid ore of a lode; an elongated pillar left to support the hanging-wall in working out a vein.
- Ribboned**—When the stratification of rocks is very distinct or strongly marked on a small scale, as by contrast of colors, such as may often be seen in gneisses, they are said to be ribboned. When the lines of contrast are on a larger scale they are said to be banded.
- Rider**— See *Horse*.
- Riddle**—A box or vessel with a perforated bottom, used by alluvial gold miners for separating out coarse gravel.
- Riffles**, See *Ripples*.
- Ring**—A gutter curb around a shaft to catch and conduct away the water.
- Ripples**—Grooves or bars across sluices for washing gold.
- Ripple-mark**—The wavy surface of some beds of sandstones and mudstones, produced by gentle movement in shallow water when these rocks were in a soft condition.
- Rise or Riser**—A shaft or *winze* excavated upward.
- Roasting**—Calcination, usually with oxidation. To drive off sulphur and arsenic.
- Rob**—To extract pillars previously left for support, or, in general, to take out ore or coal from a mine with a view to immediate product and not to subsequent working.
- Roches moutonnées**—Rounded hummocks or bosses of rock like sheep's backs, smoothed and striated by glacial action.
- Rock**—Commonly used to indicate any stony substance occurring in nature, but geologists are obliged to extend its meaning so as to include almost everything which enters into the composition of the earth, even if the material be soft like marl, clay, or sand. Rocks generally consist of mixtures of different minerals, although some, such as limestone, serpentine, quartzite, etc., are composed almost entirely of one mineral species. See *Mineral*.
- Rock-basin**—A depression or basin-like excavation in the solid rock, sometimes of great extent. Nearly all of our numerous lakes, even the largest of them, are entirely surrounded by solid rock, or lie in rock-basins.
- Rock-breaker**—Usually applied to a class of machines of which Blake's rock-breaker is the type, and in which the rock is crushed between the jaws, both movable, or one fixed and one movable.
- Rock crystal**—Transparent, colorless quartz.
- Rock-drill**—A machine for boring in rock, either by percussion, effected by reciprocating motion, or abrasion, effected by rotary motion. Compressed air is the usual motive power, but steam also is used.
- Rock-salt**—Common salt occurring in nature in solid beds or rock-masses.
- Rolley-way**—A gangway.
- Rolls**—Cylinders of iron or steel revolving towards each other, between which rock is made to pass in order to crush it. See *Roll-train*.
- Roll-train**—The set of plain or grooved rolls through which iron or steel *piles*, *ingots*, *blooms* or *billets* are passed, to be rolled into various shapes.
- Rondle or Rondelle**—The crust or scale which forms upon the surface of molten metal in cooling.
- Roof**—The rock overlying a bed or flat vein.
- Rotten-stone**—A soft light earthy substance, consisting of silica in fine grains, resulting from the decomposition of siliceous limestone.
- Royalty**—Dues paid to the lessor or landlord of a mine, or to the owner of a patented invention.
- Rullers**—The workmen who wheel ore in wheel-barrows underground.

- Run-steel*—Malleable castings.
- Rutile*—A mineral consisting of oxide of titanium. It is found associated with titaniferous iron ores and occasionally in mica-schist, granite, etc.
- Saccharoidal*—Having the texture of loaf sugar, as fine-grained crystalline limestone or marble.
- Saddle*—An anticlinal in a bed or flat vein.
- Safety-cage*—A cage with a *safety-catch*.
- Safety-catch*—An automatic device for preventing the fall of a cage in a shaft or of a car on an incline, if the supporting cable breaks.
- Salamander*—A mass of solidified material in a furnace hearth; called also a *sow* and *bear*.
- Sand-pump*—A cylinder with a valve at the bottom, lowered into a drill-hole from time to time, to take out the accumulated slime resulting from the action of the drill on the rock.
- Sandstone*—Rock composed of sand, more or less consolidated or cemented together.
- Scaffold*—An obstruction in a blast furnace above the *tuyeres* caused by an accumulation or shelf of pasty, unreduced materials adhering to the lining.
- Scale*—1. The crust of metallic oxide formed by the cooling of hot metals in air. 2. A scale of air is a small portion of air abstracted from the main current.
- Scale of Hardness*—The relative hardness of minerals is one of their most convenient tests. There are ten degrees. See *hardness*.
- Scarcement*—A projecting ledge of rock left in a shaft as support for a ladder, or to support pit-work, etc.
- Scarfing*—Splicing timbers so cut that when joined the resulting piece is not thicker at the joint than elsewhere.
- Schist*—Crystalline foliated rock, splitting into irregular lenticular or wedge-shaped plates. There are many kinds of schist, such as chloritic, talcoid, dioritic, mica, hornblende, etc. See *slate* and *cleavage*.
- Scoria* or *Scoriae*—See *slag*.
- Scouring Cinder*—A basic slag, which attacks the lining of a shaft-furnace.
- Seevin lode*—A lode having no *gossan* at or near the surface.
- Seram*—An irregular, exploratory pit or excavation, not pursued far enough to become a mine.
- Scraper*—A tool for cleaning base-holes.
- Seam*—1. A stratum or bed of coal or other mineral. 2. A joint, cleft or fissure.
- Seat*—The floor of a mine.
- Section*—In geology either a natural or an artificial rock-cut, or the representation of such on paper.
- Secular*—Relating to an age or vast period of time.
- Sediment*—Any matter such as mud, sand, etc., which has settled down from suspension in water. Most stratified or sedimentary rocks have been formed in this way, although some, as certain limestone and dolomites, have been precipitated. See *precipitate*.
- Segregation*—A process by which mineral matter has been transfused or exuded into veins and openings, especially in crystalline rocks.
- Selenite*—Gypsum in transparent crystals.
- Septum*—A division or partition, such as those in an *Orthoceras*.
- Sequence*—Following, succession, coming after, continuation.
- Sericite*—A tale-like hydrous mica (muscovite) occurring in small scales and forming sericitic schist, which is also called talcoid schist and often spoken of by prospectors as talcose schist, but this term properly applies to schists composed largely of talc, which are much rarer.
- Series*—In geology, a group of rocks in a certain order or succession, or a set of beds having something in common. See page 3.
- Serpentine*—A compact rock, rather soft or sectile, with a conchoidal and splintery fracture and waxy lustre. When powdered has a greasy feel. Capable of a high polish and is called marble. Translucent on thin edges. In color, it has various shades of green, generally dark and leek green, often spotted or veined; these are called verd-antique, also brown, red, yellowish, etc. Composed of hydrated silicate of magnesia and a little iron. The name has reference to its colors, suggestive of those of snakes.
- Set* or *Sett*—A frame of timber for supporting excavations, or the space included by the same, usually about 8 ft. x 8 ft. x 8 ft.
- Shaft*—A deep pit or hole sunk through earth or rock for the purpose of reaching minerals. Shafts are generally rectangular in cross section, and perpendicular or approximately so. If they underlie far from the perpendicular they are called slopes.
- Shaft-furnace*—A high furnace, charged at the top and tapped at the bottom.
- Shaft-walls*—The sides of a shaft.
- Shaking-Table*—A slightly inclined table to which a lateral shaking motion is given by means of a small crank or an eccentric. Water is allowed to flow over them and they are covered with copper plates coated with mercury for the purpose of amalgamating gold or silver. They may also be provided with ripples and used in separating alluvial gold.
- Shale*—Fissile argillaceous rock, splitting with the bedding as distinguished from slate, which cleaves in parallel planes independent of the bedding. Shales are generally softer than slates. There are many varieties, as ordinary argillaceous or clayey shale, bituminous (like the *Utica*) shale, arenaceous, ferruginous, calcareous, etc.
- Shambles*—Shelves or benches, from one to the other of which successively ore is thrown in raising it to the level above or to the surface.
- Shell-Marl*—A light colored calcareous deposit in the bottoms of small lakes, composed largely of dead fresh water shells, but apparently also to some extent of precipitated carbonate of lime and the hard parts of minute organisms; used for manure.

- Shift**—The time during which one set of men works in a mine. There are usually two shifts of 10 hours each in the 24 hours, but when great expedition is required three shifts of 8 hours each may be worked.
- Shift-boss**—The foreman in charge of a *shift* of men.
- Shoad**—Ore washed or detached from the vein naturally. See *Float-ore*.
- Shoading or Shouing**—The process of tracing boulders to the rock from which they came.
- Shoot**—An inclined wooden spout or slide for sending down ore or rock; also the richest ore-streaks in a vein, which in the profile of the vein may run at any angle to the horizon.
- Shooting Needle**—A sharp metal rod, to form a vent-hole through the tamping to the blasting charge.
- Shute**—See *chute*.
- Sickenig of Quicksilver**—See *Flouring*.
- Silica**—Silic. The same in composition as quartz; used more frequently in chemical language for this substance.
- Siliceous**—Relating to silica.
- Silicified**—Made into silica. Organic remains, both plant and animal, are often thus converted.
- Sill**—1. A stratum. 2. A piece of wood laid across a drift to constitute a frame with the posts, and to carry the track of the tram-way.
- Silt**—Mud, fine sand, etc., deposited in harbors, estuaries, lagoons, etc., from the slackening of the currents which had borne them along.
- Silurian System**—The third system, in ascending order, of the Palæozoic period.
- Sink-holes**—When rocks, such as salt, gypsum or limestone have been locally dissolved away, the earth may sink and form a cup-shaped basin, to which this name is given.
- Sinking-fire**—A forge in which wrought iron scraps or refined pig iron is partially melted or welded together by a charcoal blast.
- Sinuuous**—Curving, winding.
- Skep or Skip**—An iron box working between guides, in which ore or rock is hoisted. It is distinguished from a *kibble*, which hangs free in the shaft.
- Skid**—A wooden beam, scantling or other timber used in sliding heavy weights upon.
- Skimping**—See *Jigging*.
- Skull**—A crust of solidified steel lining a Bessemer ladle.
- Slab**—A wide flat stone; the outside cut off a log of wood in sawing it into planks.
- Slag**—The vitreous mass, separated from the fused metals in smelting ores.
- Stickensides**—Polished and sometimes striated surfaces on the walls of a vein or ore-deposit, or on the interior joints of the vein material or of rock masses. They are the result of movement.
- Slide**—An upright rail fixed in a shaft, with corresponding grooves for steadying the cages. 2. See *Fault, Dislocation*.
- Slime**—Natural transverse cleavage of rock.
- Slip**—A vertical dislocation of the rocks.
- Slipes**—Sledge runners, upon which a *skip* is dragged from the working breast to the tramway.
- Slit**—A communication between two levels.
- Slope**—See *Incline*.
- Sluice-Box**—A long trough or flume with ripples for catching alluvial gold when the earth is washed down it by water.
- Sludge**—Is the pumpings lifted from a churn drill, the product of the cuttings of the drill.
- Smelting**—Reducing ores by fusion in furnaces.
- Snift**—A fuse or slow match.
- Snoff**—A short candle-end put under a fuse to light it.
- Sole**—1. The bottom of a level. 2. The bottom of a reverberatory furnace.
- Solid crib-timbering**—Shaft-timbering with cribs laid solidly upon one another.
- Sollar**—A platform in a shaft, usually constituting a landing between two ladders.
- Sough**—See *Adit*.
- Sow** 1. See *Salamander*. 2. See *Pig-iron*.
- Spall or Spawl**—To break ore. *Ragging* and *cobbing* are respectively coarser and finer breaking than spalling, but the terms are often used interchangeably. Pieces of ore thus broken are called *spalls*.
- Spar**—A name given by miners to any earthly mineral having a distinct cleavable structure and some lustre; with Cornish miners generally quartz.
- Specific Gravity**—In regard to solids, means their weight relatively to an equal bulk of water at a temperature of 60° Fahr.
- Specimen**—Properly speaking, a sample of anything; but among miners it is often restricted to selected or handsome minerals, as fine pieces of ore, crystals, or pieces of quartz containing visible gold.
- Specular**—Mirror-like, as specular iron ore, a variety of hematite.
- Spend**—To break ground; to continue working.
- Spiegelisen**—Manganiferous, white cast-iron.
- Spiking-curb**—A curb to the inside of which *plank-tubing* is spiked.
- Spilling**—A process of driving or sinking through very loose ground.
- Spills**—Long thick laths or poles driven ahead horizontally around the door-frames in running levels in loose ground—a kind of *lagging* put in ahead of the main timbering.
- Spire**—The tube carrying the train to the charge in a blast hole. Also called *reed* or *rush*, because these as well as spires of grass are used for that purpose.
- Split**—To divide a ventilating current.
- Sponge**—Metal in a porous form, usually obtained by reduction without fusion.
- Sprag**—1. A prop. 2. A short round piece of wood used to block the wheels of a car.
- Spreader**—A horizontal timber below the *cap* of a set, to stiffen the *legs*, and to support the *brattice* when there are two air-courses in the same gangway.

Spreaders—Pieces of timber stretched across a shaft as a temporary support of the walls.

Sprue—A piece of metal attached to a casting, occupying the *gate* or passage through which the metal was poured.

Spud—A nail, resembling a horse-shoe nail, with a hole in the head, driven into mine-timbering, or into a wooden plug inserted in the rock, to mark a surveying station.

Spur—A branch leaving a vein, but not returning to it.

Square sets—A kind of timbering used in large spaces.

Squeeze—The setting, without breaking, of the roof over a large area of workings.

Squeezer—A machine for reducing the *puddle ball* to a compact mass, ready for the hammer or rolls.

Squib—A slow-match or safety-fuse used with a *barrel*.

Stack—A chimney.

Stalactites—Tapering, or icicle-shaped projections of travertine hanging from the roofs of caves or fissures, formed by the dripping of lime water.

Stalagmites—Of the same composition and form as stalactites, but have grown upward from floors of caves, etc., on which lime-water has dripped.

Stamper Box—See *Mortar Box*.

Stamp Head—A heavy and nearly cylindrical cast iron head fixed on the lower end of the stamp rod, shank or lifter to give weight in stamping the ore. The lower surface of the stamp head is generally protected by a cheese-shaped "shoe" of harder iron or steel which may be removed when worn out. These shoes work upon "dies" of the same form laid in the bottom of the mortar or stamper box.

Stamp Mill—A mill for stamping ores; used for reducing those of gold, silver, tin, copper, etc.

Stamps—The pieces into which the rough bars *shingled* from the flnery ball are broken, to be *piled* for subsequent rolling into sheet-iron.

Stanniferous—Carrying tin.

Steatite—Or soapstone; a massive variety of talc; a very soft rock having a soapy or greasy feel; it is a silicate of magnesia with a little water.

Steel—A compound or alloy of iron, principally with carbon, which may be cast, forged, hardened and tempered. Ordinary steel contains from 0.5 to 1.5 per cent of carbon. More carbon makes cast iron; less carbon, wrought-iron. But this classification is not now strictly adequate or applicable, either to the scientific or to the commercial use of the term. The so-called *mild* or *low* or *structural* steels (low in carbon and hence relatively soft and tough as compared with *high* or *hard* or *tool* steels, do not always harden or temper. An international committee appointed by the American Institute of Mining Engineers has recommended the use of the following classification:

1. That all malleable compounds of iron with its ordinary ingredients, which are aggregated from pasty masses, or from piles, or from any forms of iron not in a fluid state, and which will not sensibly harden and temper, and which generally resemble what is called "wrought iron," shall be called *weld-iron*.

2. That such compounds when they will from any cause harden and temper, and which resemble what is now called *puddled steel*, shall be called *weld-steel*.

3. That all compounds of iron with its ordinary ingredients, and which will not sensibly harden by being quenched in water while at red-heat, shall be called *ingot-iron*.

4. That all such compounds, when they will from any cause so harden, shall be called *ingot-steel*.

This proposed classification does not cover ordinary cast or pig iron. It is a classification of the malleable compounds only. The Institute has recommended its use in papers and discussions, except as to the term *weld*, for which a substitute was desired, and meantime the continuance of the old term *wrought*, though in a somewhat wider significance, was suggested. The resolution of the Institute concludes as follows: "It being understood that the *ingot-iron* and *ingot-steel* of this classification constitute, taken together, what is now commercially known as *cast-steel*, including the so-called low or soft cast-steels," *Bessemer steel* is made by de-carburizing cast iron in a *converter*. (See *Bessemer Process*). *Bliker* or *cement-steel* is made by carburizing wrought iron bars by packing them in charcoal powder and heating without access of air. It is melted in crucibles to *cast steel*, or hammered (*tilted*) to *shear-steel* (for cutlery, etc.), or rolled to *spring steel*. *Puddled steel* is made by arresting the *puddling* process before wrought iron has been produced, and thus retaining enough carbon in the bath to constitute steel. *Natural steel* is a similar product, obtained from the refining of cast-iron. *Crucible cast steel* is steel made by the fusion in crucibles, either of *bliker-steel* or *puddled-steel* or steel scrap, or other ingredients and fluxes which will produce the desired quality. *Cast-steel* in its widest sense, as now employed, comprises all malleable compounds produced by fusion, including, therefore, the *Bessemer* and *open-hearth* metal. *Open hearth*, called also *Martin-Siemens steel*, is made in the reverberatory furnace, (almost invariably a gas-furnace on the Siemens regenerative system, since an intense temperature is required) by the reaction, in the fused bath, of cast-iron, with wrought iron, iron-oxide or iron ore. At a certain stage of the process a *deoxidizing* or *recarburizing* agent (*spiegeleisen*, *ferromanganese*) is added. *Chrome-steel* is a crucible cast-steel in which chromium is a constituent. *Tungsten* or *Wolfram-steel* is a steel containing tungsten. *Phosphorus-steel* is a steel in which the amount of phosphorus exceeds that of carbon. *Damascus-steel* is a laminated mixture of steel and wrought-iron. *India-steel* or *wootz* is manufactured in India direct from the ore.

Stemming—The tamping put above the charge in a bore-hole.

Stempel or *Stemple*—1. One of the cross-bars of wood placed in a mine-shaft to serve as steps. 2. A *stull-piece*. 3. A *cap*, both sides of which are *hitched* instead of being supported upon legs.

- Step-vein**—A vein alternately cutting through the strata of *country-rock* and running parallel with them.
- Stock-work**—An ore-deposit of such form that it is worked in floors or stories. It may be a solid mass of ore, or a rock-mass so interpenetrated by small veins of ore that the whole must be mined together.
- Stone-head**—The solid rock first encountered in sinking a shaft.
- Stope**—To evacuate ore in a vertical or highly inclined deposit by driving horizontally upon it a series of workings, one immediately over the other or *vice versa*. Each horizontal working is called a stope (probably a corruption of *step*) because when a number of them are in progress, each working face, being a little in advance of the next above or below, the whole face under a jack assumes the shape of a flight of stairs. When the first stope is begun at the lower corner of the body of ore to be removed, and after it has advanced a convenient distance, the next is commenced above it, and so on, the process is called *over-hand stoping*. When the first stope begins at an upper corner, and the succeeding ones are below it, it is an *under-hand stoping*. The term *stopping* is loosely applied to any subterranean extraction of ore except that which is incidentally performed in sinking shafts, driving levels, etc., for the purpose of opening a mine.
- Stoping**—When a mine has been opened by sinking shafts and driving levels (called simply "sinking and driving") the next process is to stope out the ore, which consists in excavating it either upward from the roof of each level, called *over-hand stoping*, or downward from the floor, called *underhand stoping*. The latter requires all the material to be removed out of the mine, whereas by the overhand process the refuse may be left supported on stulls or flooring made of timber.
- Stopping**—1. See *Stoping*. 2. A partition of boards, masonry or rubbish, to stop the air-current in a mine, or force it to take a special desired course.
- Stowing**—A method of mining in which all the material is removed, and the waste is packed into the open space left by the working.
- Stratification**—Relating to the arrangement in strata or layers.
- Stratigraphy**—The description of stratigraphical arrangement, or its delineation on a map.
- Stratum**—A bed or layer of rock; strata, more than one layer.
- Streak**—The color of a mineral when scratched. When a mineral is rubbed on a surface of unglazed porcelain the streak is well brought out.
- Striae**—Fine parallel lines, either grooves or ridges.
- Striated**—Marked with parallel grooves or *striae*.
- Strike**—The course or bearing of the outcropping edges of inclined strata in reference to the horizon, or in other words, the strike is the intersection of the plane of the bedding with the horizontal plane. It is therefore at right angles to the dip.
- String**—A very small vein, either independent or occurring as a dropper or branch of a larger vein.
- Strip**—To remove the overlying earth and disintegrated rock from an ore-deposit.
- Structure**—The arrangement of rock-masses, such as their being bedded, jointed, slaty, schistose, basaltic, columnar, etc.; also the attitude of rocks and their positions relatively to each other.
- Studdles**—Props supporting the middle of *stulls*.
- Stull**—A platform (stull-covering) laid on timbers (stull-pieces) braced across a working from side to side, to support workmen or to carry ore or waste.
- Stulm**—See *Adit*.
- Sublimation**—The volatilization and condensation of a solid substance, without fusion.
- Sublimation theory**—The theory that a vein was filled first with metallic vapors.
- Subsidence**—A sinking down of a part of the earth's crust.
- Sulphur**—1. Iron pyrite. 2. Carburetted or sulphuretted hydrogen. In carburetted hydrogen there is no sulphur.
- Sulphurets**—The undecomposed metallic ores, usually sulphides.
- Sump**—The space left below the lowest landing in a shaft to collect the mine water. The lowest pump draws from it.
- Sump-fuse**—A water-proof fuse.
- Superficial Deposits**—Deposits forming the surface, mostly of a soft or incoherent character. In Canada they include the Pleistocene or Post-Pliocene and Recent deposits.
- Superposition**—The order in which rocks are placed above one another.
- Surface Geology**—The geology of the superficial deposits and of the surface of the fundamental rocks.
- Swab-stick**—A stick frayed out at one end; used for cleaning the sludge out of holes in process of being bored for blasting.
- Syenite**—Originally applied to a reddish crystalline granitoid rock from Syene in Egypt, consisting of feldspar, hornblende and quartz, now called quartz-syenite, while syenite has come to mean a crystalline granitoid rock consisting of orthoclase feldspar and hornblende with or without quartz.
- Synclinal**—When stratified rocks dip from opposite sides towards a common line the arrangement is called a synclinal; the reverse of anticlinal.
- System**—A great series of strata having some general character in common. As a division of the rocks of the earth's crust, the system ranks next above the formation in comprehensiveness. Formations are somewhat local divisions and many of them can only be recognized in one country, whereas the systems are sufficiently comprehensive to be recognized in all parts of the world. The systems in ascending order are Laurentian, Ontarian, Taconic, Cambrian, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Eocene, Miocene, Pliocene, Pleistocene and Recent.
- Synclinal**—The axis of a depression of the strata; also the depression itself.
- Tackle**—The windlass, rope and kibble.

- Taconic**—The Taconic system is that series of rocks containing the primordial fauna, at least that portion which is older than the New York Potsdam. It is the Lower Cambrian of English geologists, and the Huronian of the typical Huronian area of the Canadian geologists. Named from the Taconic mountains of western New England, by Dr. E. Emmons, it antedates, as a primordial system, both Cambrian and Huronian. It is the principal iron ore-bearing system of the lake Superior region, and in this Bulletin is substituted for the term Huronian, being of earlier date and less ambiguous.
- Tailings**—The fine waste material from jiggers and crushing mills. That from the latter is carried out by water and is as fine as sand.
- Tail-race**—The channel for carrying off the spent water of a mill or from a washing process.
- Talc**—A very soft mineral, being 1 in the scale of hardness; occurs in laminae like mica, but is not elastic; has a pearly luster and greasy feel; prevailing color, greenish; is a silicate of magnesia; enters into the composition of talcose schist, soapstone or steatite, the variety of granite known as protogene, etc.; is used in the manufacture of crayons, crucibles and porcelain.
- Talcoid**—Resembling talc, as talcoid schist. See *Sericite*.
- Talcose**—Containing talc; as potstone, steatite and talcose schist.
- Talcose Granite**—See *Protophene*.
- Talus**—In geology, the sloping mass of fallen rocks accumulated at the base of a cliff or precipice.
- Tamp**—To fill (usually with clay tamping) the bore-hole or other opening through which an explosive charge has been introduced for blasting.
- Tamping**—The crushed rock or other material which is hammered tightly down over the explosive in a drill-hole for blasting.
- Tamping Bar**—An iron bar, shod with copper to obviate striking fire, used for driving down the tamping.
- Tap cinder**—The cinder drawn from a puddling furnace or bloomery.
- Tap-hole**—The opening through which the molten metal is tapped or drawn from a furnace.
- Tar**—Soft pitch or thickened petroleum, found in cavities of some limestones, as those of the Corniferous formation in Ohio, also in those of the township of Keppel west of Owen Sound. Along some parts of the Athabasca river, in the Northwest territory, much mineral tar has exuded from the rocks. Common in oil districts.
- Teem**—1. To dump. 2. To pour steel from a melting-pot.
- Terra Cotta**—The "baked earth" of the Italians. Kiln-burnt clay assuming a peculiar reddish-brown color fashioned into vases, statuettes and other mouldings.
- Terra Sienna**—See *Ochre*.
- Terrace**—A nearly level shelf of land abutting on higher ground and dropping off suddenly on the lower side. This steep bank is due to the former wearing action of some body of water which cut it away.
- Terrane**—A group of strata, a zone, or a series of rocks. This word is used in the description of rocks in a general, provisional or non-committal sense.
- Tertiary Period or Age**—Also called the Cainozoic. The third grand division of geological time above the Azoic or the fourth in all. It comprises (in ascending order) the Eocene, Miocene and Pliocene systems.
- Tessellated**—A surface divided in squares, or figures approaching squares, by joints or natural divisions.
- Texture**—The coarseness or fineness, character, arrangement, etc., of the component grains or particles of a rock.
- Thermo-aqueous**—Produced by, or related to, the action of heated waters.
- Thill**—The floor of a mine.
- Thread**—An extremely small vein, even thinner than a string.
- Throw**—A dislocation or fault of a vein or stratum which has been thrown up or down by the movement.
- Thrust**—The breaking down or the slow descent of the roof of a gangway. See *creep*.
- Thurl**—To cut through from one working to another.
- Thurlings or thirlings**—Passages cut from room to room in post-and-stall working.
- Thurst**—The ruins of the fallen roof, after pillars and stalls have been removed.
- Tick-hole**—See *Vug*.
- Tull**—The Scotch name for hard-pan, boulder-clay, or the unstratified stony clays of the drift formation; a convenient term now generally adopted by geologists for these deposits.
- Titaniferous**—Carrying titanium, as titaniferous ore.
- Titanic**—See *Ilmenite*.
- Titanite**—Or sphene; a mineral consisting of silicate of titanium and lime, generally darkly colored, occurring among later crystalline rocks.
- Tilt-hammer**—A hammer for shingling or forging iron, arranged as a lever of the first or third order, and "tilted or tripped" by means of a cam or cog-gearing, and allowed to fall upon the billet, bloom or bar.
- Toadstone**—A kind of trap rock.
- Top-wall**—See *hanging-wall*.
- Tourmaline**—A mineral occurring in long, usually striated prisms in the ancient crystalline rocks; generally dark in color, harder than quartz and complex in composition, but consisting principally of silicate and borate of alumina with some iron, magnesia, lime, fluorine and different alkalies.
- Trachyte**—A volcanic rock or lava common in Tertiary and Post-Tertiary times, consisting principally of a glassy variety of orthoclase called sanidine and some triclinic feldspar, together with hornblende, mica, magnetite, etc. It is characterized by its rough fracture.
- Tram**—1. A four-wheeled truck to carry a *tub, corve* or *hutch*, or to carry coal or ore on a railroad. 2. One of the rails of a tramroad or railroad.
- Transition**—Intermediate. A term used by the older geologists for rocks which came between their better defined divisions; but little used at present.

- Translucent**—Admitting the passage of light, as milk-quartz, but not capable of being seen through.
- Transparent**—That may be seen through, as rock-crystal. Iceland-spar, selenite, etc.
- Trap**—A general term for igneous rocks, such as the greenstones, basalts, amygdaloids, some porphyries, etc., but too indefinite for modern geological language.
- Tremolite**—A variety of hornblende in radiating or columnar aggregates, generally light colored, with pearly lustre.
- Triassic System**—The first or lowest system of the Mesozoic or secondary period.
- Trilobites**—A family of crustaceans, so named from their bodies as viewed from above being divided longitudinally into three lobes. They embrace many genera and species; are most abundant in the Taconic and Cambrian systems, dying out in the Carboniferous; so that rocks in which the remains of these creatures are common may be pronounced to be below the coal bearing strata.
- Tributer**—One who works a mine or mineral deposit for a share of the product.
- Truncated**—Cut or broken off abruptly.
- Trolley**—A small two or four-wheeled truck without a body.
- Trouble**—A dislocation of the strata.
- Trough**—In geology, synonymous with *Basin* and *Synclinal*, which see.
- Truck**—A small tram-car for carrying coal, rock or ore along a level in a mine, or out to a shoot or a dump. Also goods paid instead of money for wages.
- Tubbing**—A shaft lining of casks or of cylindrical caissons, of iron or wood.
- Tubing**—Lining a deep bore-hole by driving down iron tubes.
- Tufa**—Any open, porous or vesicular mass, as volcanic tufa, calcareous tufa, etc.
- Tug**—The iron hook of a hoisting bucket, to which the *tackles* are attached.
- Tunnel**—1. A nearly horizontal underground passage, open at both ends to day. 2. See *Adit*.
- Tunnel-head**—The top of a *shaft-furnace*.
- Turn**—A pit sunk in a *drift*.
- Turn-bat**—A wooden stick used in turning the tongs which hold a *bloom* under the hammer.
- Turtle-stones**—Large nodular concretions found in certain clays and marls. In form they have a rough resemblance to turtles, and this appearance is increased by their being divided into angular compartments by cracks filled with spar, reminding one of the plates on the shell of a turtle. They are common in the Cretaceous marls of the western states and territories.
- Tuyere, Tweer, Tuyer, Tuere**—A pipe inserted in the wall of a furnace, through which the blast is forced into the furnace. Usually the tuyere enters through an embrasure in the masonry (*tuyere-arch*). A nozzle or interior pipe is frequently inserted at the inner end of the *tuyere*. By changing the nozzle, the size of the opening for the blast may be thus regulated without changing the *tuyere*. The latter is either an annular hollow casting of iron (*box-tuyere*) or bronze, (*bronze-tuyere*), or a coil of iron pipe. In either case water is continually circulated through it to protect it and the nozzle from the action of the melting materials in the furnace. *Spray-tuyeres* are open *box-tuyeres* in which a spray of water instead of a current, is employed. This is vaporized by the heat, and passes away as steam.
- Tuyere-Plate**—See *Bloomery*.
- Tymp**—A hollow iron casting, cooled interiorly by a current of water, and placed to protect the *tymp-arch*, or arch over the *dam* in a blast furnace having a *fore-hearth*. (See *Open front*.)
- Unconformable**—See *Conformable*.
- Unctuous**—A greasy feel such as that of soapstone, powdered serpentine, certain clays, etc.
- Under-hand**—See *Stope*.
- Underlie or Underlay**—The departure of a vein or stratum from the vertical, usually measured in horizontal feet per fathom of inclined depth. Thus a *dip* of 60° is an *underlay* of three feet per fathom. The *underlay* expressed in feet per fathom is six times the natural cosine of the angle of dip. See *Dip*.
- Undisturbed**—Rocks which lie in the positions in which they were originally formed. See *Disturbed*.
- Univalve**—A mollusk having a single shell. A bivalve mollusk has two shells.
- Unstratified**—Rocks which are not in beds or strata, as granite, syenite, greenstone, etc.
- Unwater**—To drain or pump water from a mine.
- Upcast**—1. The lifting of a coal seam or ore bed by a dyke. 2. The opening through which the ventilating current passes out of a mine. See *Downcast*.
- Upheaval**—A lifting up, as if by some force from below, of stratified or other rocks.
- Uphrow**—An upward displacement of rock along a line of break or fissure.
- Vamping**—The *débris* of a stope, which forms a hard mass under the feet of the miner.
- Vein**—A fissure, a contact-space, or a gash which has been filled with mineral matter. After a rent or fissure has been formed in solid rock, there is usually some dislocation, so that a space is left between the walls. This gives rise to the fissure vein. Similarly a movement or dislocation along the contact of two different kinds of rocks gives rise to the contact vein. A gash vein terminates in a thin edge in all directions or has a lenticular form, and is only exposed so that it may be discovered by a natural section of the rock formed either by the surface of the ground or by a cliff.
- Veinstone**—The mineral matter filling a vein, exclusive of the ore. See *Gangue*.
- Veined**—Marked or streaked with veins or lines of color in various directions, as some marbles.
- Verd-antique Marble**—A variety of green serpentine with patches and veins of white calcspar and capable of a fine polish.
- Verifier**—A tool used in deep boring for detaching and bringing to the surface portions of the wall of the bore-hole at any desired depth.

- Vermilion*—The lowest of the stratified schists; [the crystalline schists. Dr. Lawson named them *Coulchiching*.
Vermilion—A bright red pigment consisting of the sulphide of mercury. See *Cinnabar*.
Vertebra—A joint of the backbone of any vertebrate animal.
Vertebrata—One of the provinces or primary divisions of the animal kingdom.
Vesicular—Containing little bladder-like cavities, such as some lavas.
Vitreous—Like glass.
Vitrify—To make like glass.
Volcanic—Pertaining to volcanoes. Volcanic rocks are those of igneous origin formed at or near the surface, such as lava, amygdaloid and volcanic ash; whereas igneous rocks formed at a depth and under pressure are generally crystalline and are called plutonic. See *Igneous*.
Vug, Vugg or Vugh—A cavity in the rock or ore, usually with a crystalline incrustation.
- Wad-hook*—A tool with two spiral steel-blades for removing fragments from the bottom of deep bore-holes.
Wall—1. The side of a level or drift. 2. The *country-rock* bounding a vein laterally.
Wall-plates—The two side-pieces of a timber frame in a shaft, parallel to the strike of the lode when the shaft is sunk on the lode. The other two pieces are the *end-pieces*.
Waste—Old workings. The signification seems to include that of both *goaf* and *gob*.
Weather-door—A door in a level to regulate the ventilating current.
Weathering—Changing under the effect of continued exposure to atmospheric agencies.
Wedging-curb or Wedging-crib—A *curb* used to make a water-tight packing between the *tubbing* in a shaft and the rock-walls, by means of split *deals*, moss and wedges, driven in between the *curb* and the rock.
Weld—To join pieces of metal by pressure, at a temperature below that of complete fusion.
Whim—A large drum for winding rope, revolving horizontally and kept in its place by a frame-work. It is worked by a horse or horses attached to a long horizontal beam placed under the drum.
Whin or Whinstone—Basaltic rock; any hard, unstratified rock; greenstone.
Whip—A beam over a shaft, with a pulley and rope for raising or lowering a bucket or kibble. This is done by means of a horse going forward and back again.
Win—To extract ore.
Winch or Windlass—A man-power hoisting machine, consisting of a horizontal drum with crank handles.
Winding—Hoisting with a rope and drum.
Winds—See *Winze*.
Winning—A new opening.
Winze—An interior shaft, usually connecting two levels.
Work—Ore not yet dressed.
Working home—Working toward the main shaft in extracting ore or coal, as in *longwall retreating*.
Working out—Working away from the main shaft in extracting ore, as in *longwall advancing*.
- Zeolites*—A numerous family or group of minerals, found chiefly in volcanic rocks. In composition they are allied to the feldspars, but contain water in addition.
Zinc blende—Natural sulphide of zinc. A crystalline mineral with a bright resinous lustre; generally of resinous or dark color; gives a white streak. See *Blende*.
Zircon—A hard and heavy mineral found in granitic rocks. It consists of silicate of the metal zirconium. The commoner varieties are generally of a reddish-brown color. When transparent it is prized as a gem.
Zone—In geology, used in the same sense as horizon, to indicate a certain geological level or chronological position, without reference to the local attitude or dip of the rock, as the Primordial or Taconic zone.

APPENDICES.

APPENDIX A.

ON A POSSIBLE CHEMICAL ORIGIN OF THE IRON ORES OF THE KEEWATIN IN MINNESOTA.*

BY

N. H. WINCHELL AND H. V. WINCHELL.

The proper understanding of the limits of this discussion requires a brief statement of some recent stratigraphic determinations. It is evident that the papers of the late Prof. R. D. Irving† and of Prof. C. R. Van Hise‡ while in the main considering the problem from the point of view of the "Huronian," have also embraced within the scope of the phenomena cited, a group of strata much older, which lie everywhere,§ unconformably under the Huronian, and which present a series of facts which are distinct from those appertaining to the Huronian as found in the Penokee-Gogebic and Mesabi regions. The confounding of two formations, and the placing in one category the chemical and structural phenomena that are separated into two series by a great time-interval, and by structural unconformity, have so complicated the problem that hitherto no theory has been found capable of covering all the facts. The existence of this widespread unconformity has been shown in recent reports on the geology of the northwest by A. C. Lawson, A. Winchell and the writers; and latterly it was also recognized by Irving.|| By Prof. Irving, however, there had not been, prior to his death, so far as known, any reconstruction or limitation of his general theory of the origin of the iron ores.

It is the purpose of this paper, while not calling in question the explanation by Irving of the origin of the ores of the Huronian, to

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†*Am. Jour. Sci.*, (III), xxxii, 255.

‡*Am. Jour. Sci.*, (III), xxxvii, 32.

§Compare the 17th An. Rep. of Minn. Geol. Surv., pp. 42-45.

||*Seventh An. Rep. U. S. Geological Survey*.

show specifically, a possible origin for those of the Keewatin as they are found in the Vermilion range in Northeastern Minnesota.

That there is reason to account for the Vermilion ore on a different hypothesis from that which may be sufficient for the Huronian ore, is evident from a consideration of the following differences in the formations. The Huronian strata are of fragmental origin, accumulated by the slow process of sedimentation, and are siliceous; being banded by lines of deposition that fade from one sort into another by such insensible transitions as can be produced by successive variations in the forces of an ordinary sedimentary process. This structure not only pervades the rock that embraces the ore, but passes into the ore itself. The formation as a whole, and certainly the beds that embrace the ore, are made up of secondary grains derived from some other formation. In other words it is non-crystalline. (Irving, 3d An. Rep. U. S. Geol. Sur., pp. 157-165; 16th An. Rep. Minn. Sur., p. 39.)

On the other hand, the strata that carry the iron ore depositos the Keewatin, when not rotted *in situ*, are crystalline or sub-crystalline, and do not vary in composition like a sedimentary rock. They do not show, except very rarely, any transitions between the ore and the enclosing rock, and when they do show such a mingling the alternations are between the two kinds of material, and without the intermixture of clayey substances. The two materials are the *ore itself* and the *country rock*. But the country rock is uniformly constituted of diabasic schist which shows either its direct origin from eruptive, basic rock, or its quick distribution and deposition in waters heated by volcanic disturbances; and but rarely has so much intermingled silica of secondary, sedimentary derivation, as to raise the per cent. of silica above the limit of Von Cotta for a basic rock. At points remote from the ore lodes the proportion of silica increases, and it is besides not wholly of the characteristic chalcedonic sort that prevails in the ore and in proximity to it. But, instead, some part of the silica found in strata distant from the ore lodes is in the form of rounded grains of vitreous quartz such as is chemically deposited in ordinary quartz veins. Besides silica, an aluminous element also displays itself in the formation at points removed from the mines.

Another noticeable difference between the Huronian and the Keewatin ores consists in the gradual changes that are seen to occur in the Keewatin ore as the country rock becomes more and more crystalline, massive and diabasic. In passing eastward from Tower the hematite is seen to give place gradually to magnetite, *pari passu*, as the green schists assume the character of unmodified

diabase; and in the vicinity of Snowbank lake the iron ores are magnetitic jasperoid lodes embraced in such massive diabase,* conforming in general with the strike of the rocks of the region, and still showing all their necessary relations to the Keewatin formation. These characters are found, not in the lower, often lake-filled, valleys, but on the hills at elevations of several hundred feet. No such phenomena have ever been reported from the Huronian. The eruptive, diabasic rock of the Huronian mines either underlies the iron-bearing strata unconformably, as described by Dr. Rominger, or is in the form of transverse dikes that cross both the country rock and the ore-beds, as recently described by Van Hise.†

Not only in respect to age and geological relations do these ores differ, but chemically they are quite different. The points of dissimilarity are prominently revealed in making a comparison of their impurities. The Keewatin ores contain silica as their chief impurity, the amount of phosphorus, determining the Bessemer or non-Bessemer grade, not being noticeably different from the Huronian ore. But in respect to other impurities the Huronian ores contain about 300 per cent more manganese; about 400 per cent more sulphur; about 33 per cent more alumina; about 25 per cent less magnesia; about 400 per cent more lime and about 400 per cent more water.‡ The Huronian ore is generally soft, and sometimes is a limonite passing to siderite. The Keewatin ore is hard, never limonitic, and has not been known to contain any carbonate of iron.

The objections to the eruptive hypothesis of Foster and Whitney, lately revived by Dr. Wadsworth, have been stated in the fifteenth report of the Minnesota survey, and it is not necessary to dwell upon them here. The extreme length to which Dr. Wadsworth is carried by his predilection for eruptive agencies is seen in his arguing|| that the quartzite at Republic mountain is eruptive. One of the chief obstacles to this theory is the novelty of the proposition to enclose fused silica in the same mass with crystalline hematite and require them to cool without chemical union, the former retaining an amorphous state and the latter not losing its crystalline structure. Another obstacle is the plainly sedimentary banding that the ore presents, *i. e.*, the jaspilite, which is unlike any structure known to result from the cooling of molten

**Am. Geol.*, Jan. 1889, p. 19; 17th Rep. Minn. Sur. p. 122.

†*Am. Jour. Sci* (III), XXXVII, 32.

‡These results are based on average analyses for 1888, published by Pickands, Mather and Co., derived from several thousand assays.

||Notes on the Geology of the Iron and Copper districts. *Bul. Mus. Comp. Zool., Geol. Series*, Vol. I. p. 54.

rock, and which unmistakably reveals the action of water in the formation of long parallel bands or strata.

The difficulties of applying the theory of Irving, *i. e.*, the metasomatic substitution of oxides of iron for some pre-existing carbonate, appear when we search for the remains of the supposed older carbonate; and when we find that the country rock does not afford good reason to have expected the deposition of any carbonate; and also when we search for the remaining ingredients which the assumed metasomatic process may have left in the ore. In short, the whole mass of geological and mineralogical environment, as seen in the Huronian rocks, is at variance with that seen in the Keewatin, and precludes the hypothesis that ordinary chemical substitution will account for the chalcedonic silica and the hematite of the jaspilite lodes.

But that chemical processes played a prominent, if not a principal, part in the formation of the jaspilite, and in the metamorphism of the strata of all the Archæan, there is no disposition to call in question.* They are here appealed to as the prime agent in giving origin to the chalcedonic silica and the iron ore of the jaspilite.

In order that the physical circumstances which obtained during the age of the crystalline and sub-crystalline schists, *i. e.*, during the age of the Vermilion and of the Keewatin, may be fairly apprehended, and brought to bear upon this inquiry, it will be necessary to mention some inferences that have recently been wrought out by the study of the Archæan.†

It has been stated repeatedly, by G. M. Dawson,‡ by A. C. Lawson§ and by the writers,|| that the rocks of the Keewatin consist very largely of volcanic ejectamenta. These ejectamenta were received in oceanic waters. The volcanoes themselves were mainly submarine, and the products of any intervening stage of sedimentary quiet were buried under the lavas of the next quickly succeeding stage of eruption. Whether this eruptive stage was world-wide, in its production of this kind of basic schist, as seems very likely, it is not necessary here to inquire; but that it was one of great duration, and prevailed in all of northeastern Minnesota wherever this rock horizon has been examined, and extended into Manitoba, there is no longer any room to doubt. It is therefore

*A. Winchell, *Fifteenth Report, Minnesota Survey*, p. 196.

†*Seventeenth Annual Report, Minnesota Survey*, pp. 37-40.

‡*Geology and Resources of the 49th parallel*, 1875, p. 52.

§*Geology of the Lake of the Woods*, Can. Survey Rep., 1885, C. pp. 49-54.

||*Fifteenth report, Minnesota Survey*, 1886, p. 221; *16th Report*, p. 108; *17th Report*, p. 37; *Am. Geologist*, Jan. 1889, Vol. iii, p. 22. Compare, also, Foster and Whitney, on the "Azoic," *Report on the Lake Superior land district*, 1851, Part ii, p. 67.

necessary to inquire how such products as chalcedonic silica and hematite could have been formed in a sea that was at times seething and steaming with volcanic craters and earth-fissures, from which escaped molten material from below the thin crust. That this chalcedonic silica, involved closely with interbanded hematite, and grading into it by insensible variations in the amount of iron present, was received in water and distributed by water, is indicated not only by the stratiform arrangement, but also by the presence, occasionally, but very rarely, of rounded grains of other silica, not chalcedonic, some of them being a quarter of an inch in diameter, embraced in the general mass of the jaspilite and sometimes forming more or less distinct belts or pebbly patches in the jaspilite, approximately parallel with the general strike. This fact effectually vetoes the eruptive theory, and demonstrates that there was no exception in favor of that theory, so as to produce a structure characteristic of sedimentation, through the agency of molten acid lava flows.

When the character of some of the narrow bands of pure white and translucent silica is duly considered, and it is compared with the known product of chemical precipitation from siliceous waters, the idea of *chemical precipitation* is forcibly presented as the possible origin for the chalcedonic silica of the jaspilite. There is no way known in nature for the formation of chalcedonic silica except by chemical deposition. The different bands of the jaspilite, varying in color from white to red, brown and sometimes nearly black, are all formed by the varying proportions of hematite and silica. Ordinary sedimentary action could not select from the products of erosion simply two substances and unite them in characteristic strata, when the ocean's waters must have been charged with suspended matter of many different kinds. Some selective, discriminating force was at work which was able to abstract silica, or silica and iron oxide, from the water and reject all the rest.

In the light of what has already been said regarding the nature of the schists enclosing the ore masses, it is plain that the waters of the Keewatin ocean were constantly agitated by volcanic eruptions. It is also plain that they must have been hot, and in some places, or after irregular intervals of time, must have been rapidly evaporated and at other times suddenly cooled. The earth's crust was thin and easily rent, and the contact of water and molten rock was frequent. The water became alkaline by solution from the lavas of the magnesia, potash and soda and other alkaline elements. In this condition it would also become surcharged with soluble silica and iron, obtaining the latter from the augitic minerals of the

basic lavas, and possibly from masses of erupted metallic iron. Indeed, the ocean was a hot compound decoction of all the minerals that could be dissolved from the eruptive diatases; and of those minerals there was no exception.

Under such circumstances it requires no extensive research nor chemical foreknowledge, to predict what would be the result whenever the equilibrium of super-heated and super-saturated oceanic water was disturbed. Something would be precipitated. Would it be silica and ferric oxide?

On this point Hunt says:* "The atmosphere, charged with acid gases which surrounded the primitive rock, must have been of immense density. Under the pressure of such a high barometric column, condensation would take place at a temperature much above the present boiling point of water; and the depressed portions of the half-cooled crust would be flooded with a highly-heated solution of hydrochloric and sulphuric acids, whose action in decomposing the silicates is easily intelligible to the chemist. The formation of chlorides and sulphates of the various bases and *the separation of silica* would go on until the affinities of the acids were satisfied, *and there would be a separation of silica, taking the form of quartz*, and the production of a sea-water holding in solution, besides the chlorides and sulphates of sodium, calcium and magnesium, salts of aluminum and other metallic bases.'

. . . . "Quartz has not only never been met with as a result of igneous fusion, but it is clearly shown by the experiments of Rose that a heat even much less than that required for the fusion of quartz destroys it, changing it into a new substance, which differs both in chemical and physical properties from quartz."

"The first precipitates from the waters of the primeval sea must have contained oxidized compounds of most of the heavy metals."

"The large amounts of silica contained in solution in the waters of some thermal springs and of many rivers, are separated when these waters are exposed to spontaneous evaporation, partly as silicates of lime and magnesia, and partly in the forms of crystallized quartz, hornstone and opal. In many different formations beds are met with composed entirely of crystallized grains of quartz which have apparently been deposited from solution. In other sediments this element abounds in the form of grains of chalcedony or as amorphous soluble silica. The beds and masses of chert, flint, hornstone, buhrstone, and many jaspers, have all apparently been deposited from aqueous solutions."†

*T. Sterry Hunt. *The Chemistry of the Primeval Earth. Am. Jour. Sci., Jan., 1858; Smithsonian Report, 1869, p. 189; Chemical and Geological Essays, 1878, p. 40.*

†Hunt, *Geology of Canada, 1863, p. 574.*

Prof. A. Winchell thus refers to this primeval ocean and the precipitation of silica:* "The liberated silica would separate and would be chemically precipitated during the subsequent cooling of the waters, and would thus give rise to the enormous beds of quartz which we actually find among the very oldest strata."

Concerning the similar production of beds of iron oxide, Hunt states:† "Those chemical compounds which were most stable at the elevated temperature then prevailing would be first formed. Thus, for example, while compounds of oxygen with mercury, or even with hydrogen, could not exist, oxides of silicon, aluminum, calcium, magnesium and iron might be formed. . . . All the elements, with the exception of the noble metals, nitrogen, chlorine, the related haloids, and the hydrogen combined with these, would be united with oxygen. The volatility of gold, silver and platinum would keep them still in a gaseous condition at temperatures where silicon, and with it the baser metals, were precipitated in the form of oxides."

These quotations might be multiplied. The formation of siliceous and iron deposits from oceanic waters is referred to by Gustav Bischof,‡ J. W. Dawson,|| and by nearly all geologists who have written of the chemical reactions of the primeval ocean. Much speculative literature has been published relating to the early co-relations of the consolidating crust, the heated interior and the enveloping atmosphere of the earth. But very often no actual account has been taken of these theories in the practical work of field geologists. The drama of sedimentation, and the erosion of shores, and the transportation of material by currents, forming the later strata of the super-crust, have been duly investigated, but this theoretical age of seething, alkaline, oceanic water, the actual causes that produced it, the resultant rocks that attest its existence and the position it holds in the strata of the Archæan, have not had their analogous demonstration and adequate description in geological literature. The writers believe that the Keewatin age was characterized by these forces and events and that the green schists, whether sericitic or chloritic or diabasic, that fundamentally constitute the bulk of its rocks, and the jaspilite lodes, exemplify the chemical precipitations and the mechanical depositions that the theories require. So long as the term "Huronian" was made to cover the actual Huronian strata, as well as all lower beds down to the Laurentian base, it was difficult,

*A. Winchell, *Sketches of Creation*. 1870, p. 59.

†T. Sterry Hunt, *Smithsonian Report*, 1869, pp. 186, 189.

‡*Chemical and Physical Geology* (Cavendish Society), Vol. I, pp. 143, 146.

||*Quart. Jour. Geol. Soc.*, Vol. V, p. 25.

if not impossible, to invoke world-wide forces in one portion of the stratification that nullified those that were demanded to produce the rocks of the other. By the separation of the Keewatin from the Huronian a different set of conditions may be relied on, but none other than those that are needed to produce the rocks which are found to compose it.

It is not the purpose of this paper to explain any of the physical conditions of the jaspilyte, nor of the strata that compose the bulk of the Keewatin, such as brecciation, folding and involute contortion, compression, fracturing and transportation of strata once formed, the upheaval and prevailing verticality of the beds. These, in the main, must have been produced subsequent to the chemical precipitation here appealed to to explain their origination, but to a certain extent seem to have been contemporary with the precipitation of the beds themselves. But it is our sole purpose to account for the existence of the jaspilyte by some hypothesis consistent with known chemical laws, and in accordance with such surroundings and physical forces as the nature of the Keewatin rocks shows to have obtained at the time of its formation. This hypothesis not only is consistent with these laws and conditions, but it explains some of the features of the jaspilyte which no other theory, so far proposed, will explain. Some of these peculiar features may be mentioned, namely: (1) It accounts for the minutely fine structure of the silica, and for the uniformity of its granular texture upon disintegration; (2) It accounts for the prevalence of this structure at all depths in the earth, wherever the jaspilyte is found to extend; (3) It accounts for the agate-like banding and the minuter lamination that characterize the jaspilyte; (4) It furnishes an explanation for the purity of the white chalcedonic ribbons which consist of silica only; (5) It explains the re-cementation of some of the thin, brecciated layers by material of the same kind as the layer itself; (6) It explains the occasional intrusion of rounded grains of non-chalcedonic quartz into the mass of chemically precipitated quartz; (7) It explains, lastly, the occasional mingling of chalcedonic silica with the finer elements of the basic schists, forming regular sedimentary alternations.

Summary. All attempts hitherto made to account for the existence of the iron ores of the Northwest, particularly those of professors Irving and Van Hise, have confounded the phenomena of two unconformable formations that manifest constantly distinct contrasts of stratigraphy and lithology.

The theory of Foster and Whitney, that these ores are of eruptive origin, is opposed by chemical laws and by structural peculiarities that cannot be reconciled with it.

The ores of the Keewatin are markedly different from those of the Huronian in their chemical impurities.

The theory of metasomatic substitution of iron oxide for some carbonate, while applicable to the ores of the Huronian on the south side of lake Superior, cannot be made to account for the ores of the Keewatin, because, (1) There is no evidence of the existence, at any time, of the necessary earlier carbonate, and (2) The nature of the country rock embracing the Keewatin ore is such as to imply that no carbonates, in the amounts required by the theory, could have been deposited at the time the rocks were being formed.*

There is, therefore, necessity for some other explanation than that applicable to the Huronian ores.

Chemical precipitation in hot oceanic waters, united with simultaneous sedimentary distribution might produce the Keewatin ores in a manner consistent not only with the physical conditions that prevailed at the time of their formation, and with the structural peculiarities which they exhibit, but also in accordance with the known reactions of heated alkaline waters, and with the chemical character which the ores are known to possess.

*This statement should have some modification. Later microscopic examination has shown, as illustrated by plate viii, pages 76 and 77, that occasionally fragmental grains of dolomite are mingled with the chalcedonic silica grains. Their present position seems to be due to mechanical deposition, and they may have been transported from their parent sources by currents in the ocean and mixed with the chemically precipitated silica. Such dolomitic, cherty jaspilyte, however, is very rare in the Keewatin.

APPENDIX B.

THE TACONIC IRON ORES OF MINNESOTA AND WESTERN NEW ENGLAND.*

BY N. H. WINCHELL AND H. V. WINCHELL.

In the course of an investigation and report on the iron ores of Minnesota we have learned that there are five principal kinds of ore, and that while they differ mineralogically one from the other, and are associated with different mineral species, they also belong to different geological horizons. These five ores are as follows:

1. The hematites and limonites of the "Mesabi range," the equivalent of the manganesic hematites of the Penokee-Gogebic range in Wisconsin.

2. The gabbro-titanic magnetites, whose stratigraphic place is near the bottom of the rocks of the Mesabi range.

3. Olivinitic magnetites, and sometimes sulphur-bearing quartzose magnetites, whose place is just below the gabbro eruptive rock and in the basal portion of the Mesabi rocks.

4. The hematites and magnetites of the "Vermilion range," extensively worked at Tower, belonging in the Keewatin formation.

5. The magnetites of the crystalline schists belonging in the Vermilion formation.

In our discussion of these ores we have attempted to indicate their probable equivalents, as to quality and stratigraphic horizon, in Canada and in the eastern portion of the United States. We have little or no difficulty in designating those ores which, in stratigraphic position, as well as in metallurgical quality, are the probable parallels of the northwestern ores. These discussions and comparisons will appear in a forthcoming bulletin (No. 6) of the Minnesota Geological Survey.

In the consideration, however, of the ores of the Mesabi range we have been led into a somewhat extended re-examination of the literature of the ores of eastern New York and of western New England, and we desire to call the attention of geologists to some of the results.

*Read before the Geological Society of America, Indianapolis, Aug. 22, 1890. Published in the *American Geologist*, Vol. vi, pp. 263-274, November, 1890.

We have for some time considered the Mesabi hematites and limonites, which are the unquestioned equivalents of the manganesic hematites (with small amounts of limonite) of the Penokee-Gogebic range on the south side of lake Superior, as belonging in the primordial zone of the stratigraphic scale. It is not likely that any one will question this conclusion, as it has lately been confirmed by the discovery of primordial fossils in the Animike rocks of this region at points a few miles north of the international line. The fossils have been examined and pronounced upon by Prof. G. F. Matthew.* It is in connection with the ores that occur in these rocks (making the Mesabi iron range in Minnesota) which we designate Taconic that we desire to offer some remarks touching their probable eastern equivalents.

We were at once struck with their general appearance of parallelism with the Taconic ores of western New England. This general appearance is found to characterize them as ores and as parts of their associated geological terranes. For instance, if we consider their quality, they are both characterized as limonitic hematites, easily mined and often manganesic, and they have each been traced back to a carbonate as their original condition. The early speculation of Dewey that they were of derived origin was seconded by the elder Hitchcock, with a designation of the nature of that original condition, and has been followed by Dana and lastly by Irving and Van Hise, and by J. P. Kimball in almost a complete demonstration that the ore of this geological horizon, or of these two horizons, was at first in the form of some carbonate, which was largely carbonate of iron. The removal of the carbonic acid, resulting in the oxidation and concentration of the iron, by surface waters, has caused locally large deposits of rich iron ore.

If we consider further this general appearance of parallelism in respect to their associated rock strata we find also a striking similarity. We know that the western ores of this horizon are uniformly found in close association with a dolomitic limestone, which is often quite siliceous or "cherty." It often embraces lumps, and apparently angular pieces of flint and jasper of bright colors. It has been described at some length by Irving and Van Hise in their late discussions of the iron ores of Wisconsin.† They estimate that this limestone is sometimes 300 feet thick, and that in other places it is apparently wanting. It has been described as marble where it appears at Menominee, but generally it is not in sufficiently large and even masses or beds to warrant that designation. It

**Am. Jour. Sci.* (3) xxxix, 145.

†*Am. Jour. Sci.* (3) xxxvii, 32.

also appears at the same stratigraphic horizon in Canada, according to the descriptions of the Thunder Bay region by the Canadian geologists. In Canada, however, and in northeastern Minnesota, it has not attracted so general attention, either because it is not so largely developed, or because it has not yet been discovered in outcrop on so large a scale. Underneath this limestone, in Minnesota, is a conspicuous and persistent quartzite, which sometimes is vitreous. This is cut and interbedded with gabbro, and in large tracts is immediately overlain by the great gabbro sheet of that part of the state. This quartzite has an observed thickness, in Minnesota, of not over 300 feet, but it may be over 500 feet thick. In Wisconsin it is estimated at 300 feet. Overlying the limestone, at least at a higher stratigraphic horizon (though the limestone may be wanting where this observation was made) are other quartzose strata, differing considerably from the lower quartzite in being finer grained and often with limonitic streaks. Overlying all these strata are black slates with interbedded traps, passing upward into the quartzites and traps of the Cupriferous (Keweenaw) formation of lake Superior.

If we compare this succession of strata with that of the Taconic region of western New England, we are at once impressed with the close resemblance. Overlying the Archæan of the Green mountains is the great "Granular quartz" which has lately been shown by fossils to belong to the primordial zone,* and which Dr. Emmons put at the base of his Taconic system. Above this is the great *marble belt*, which Prof. Dana has traced, under the guide of lithological characters and general stratigraphy, from central Vermont to New York city, and which at Cortland is overwhelmed, along with the underlying quartzite, by the gabbro of the Cortland series. This marble Dr. Emmons styled Stockbridge limestone, and in his scheme he considered it as immediately superjacent to the granular quartz. It is in this limestone, or in immediate proximity to it, that occur all the iron ore beds of western New England and of Dutchess, Columbia and Rensselaer counties in New York. Prof. Dana has called attention to this association. Dr. Hitchcock had done the same earlier. That this limestone, which furnishes large quantities of marble, which holds the limonites of the region, which immediately overlies a great quartzite, which is primordial, which has a dolomitic composition, and which is overwhelmed with a gabbro outburst, should have an exact parallel in all these respects in the Northwest, is certainly a remarkable coincidence of geological data that demands close at-

*C. D. Walcott. *Bulletin No. 30, U. S. Geol. Survey.*

tention. These are the general considerations that impressed us with the probable parallelism of the Taconic ores of Minnesota with those of western New England.

But we meet here the obstacle, that Prof. Dana has investigated the Stockbridge limestone, has traced it into immediate connection with a fossiliferous limestone, and that the fossils there found were those characteristic of the Trenton limestone. He has pronounced the Stockbridge limestone identical with the Trenton-Chazy-Calciferous. In more recent times Mr. C. D. Walcott has come to the same conclusion. We need not refer specifically to their papers. They extend in the volumes of the American Journal of Science from 1872 to 1889. The mainspring which actuates them all is, apparently, the overthrow of the Taconic system.

We were forced, therefore, either to seek for some other explanation of this coincidence, or to abandon the effort to find an eastern representative of the western Taconic ores, or to correct the interpretation that had been put on the stratigraphy of one or the other.

To attempt to explain this coincidence on the supposition that the limestones and quartzites concerned are on separate horizons, without an investigation of the evidence, was to traverse the manifest dictates of human intelligence. To abandon the effort to suggest a probable eastern representative of the Taconic ores of the Northwest, in the presence of a strongly suggested equivalent, notwithstanding the necessity of a laborious reconsidering of the whole question, both in the west and the east, was to make a hiatus in our investigation, and was to quail at the appearance of added work. We therefore decided to undertake to re-examine the problem. It was divisible into two parts which pertain to:—

1. Can there be any mistake in the stratigraphy of the Northwest, such as would, if corrected, allow of this quartzite, and this limestone (and particularly this limestone) being put into the strata of the second fauna?

2. Can there be any mistake in the stratigraphy of western New England, which, if corrected, would allow of the Stockbridge limestone being put into the Primordial zone?

It did not require a moment to answer the former question. There is no geologist who has examined the rocks of lake Superior who would not at once scout the idea of the Trenton age of any limestone in northeastern Minnesota. No one has ever suggested such a possibility.

We were therefore forced to seek for possible mistakes in the stratigraphy of western New England, as recently interpreted by Messrs. Dana and Walcott.

At the outset we find great confusion in the stratigraphy of western New England. If there be any part of the world where the strata have been differently interpreted, it is the Taconic region. Dr. Emmons' scheme was opposed by an influential school during his lifetime, but was virtually accepted when Barrande and Billings espoused his views on paleontological grounds. There were so many apparent irregularities and exceptions, not to say errors, in the stratigraphy of Emmons, that Prof. Dana reviewed the whole field on lithological and general stratigraphic lines, and reached the conclusion that Emmons was wholly wrong, and that the Taconic system had no actuality as a sub-Silurian (primordial) terrane, but that all the rocks included in it were of the age of the Champlain system of New York. Again, and lastly, Mr. Walcott has gone over the ground, in some parts of the field, and has found fossils enough to establish a great primordial (sub-Silurian) series, correcting Dana in respect to the quartzite and the "great central slate belt," but approving Dana in respect to the Stockbridge limestone.

Now, it is this final conclusion, respecting this limestone, to which we wish to direct your attention. Does it belong chronologically immediately above the quartzite, and thus near the base of the primordial, or does it belong in the zone of the second fauna?—the equivalent of the Trenton, or the "Trenton-Chazy-Calceiferous?"

It is but just to Mr. Walcott to state that he did not give much attention to the stratigraphy of the eastern portion of the limestone belt in Vermont and Massachusetts, but accepted and expressed on his map accompanying his last papers in the *American Journal of Science*,* the conclusions of Prof. Dana, who, again, accepted and perpetuated the conclusion of Rev. Mr. Wing, to the effect that the Stockbridge limestone and the Sparry limestone are the same stratum, in general, and that the differences of lithology, as well as the noticeable lack of fossils in the Stockbridge, or eastern belt, are due to greater metamorphism toward the east.

In considering the possible distinctness of these two limestones, there are some things that must be accepted as facts that cannot be questioned. In general, all those facts of observation that have been stated by good geologists have to be admitted. It is only when inferences have been drawn from the facts which the facts do not prove, that we are at liberty to suggest other inferences.

To begin with, then, we must admit there are sufficient facts already published by Messrs Wing and Walcott, to prove the exis-

*Op. Cit., vol. xxxv.

tence of the Trenton limestone in the region, and we may admit that it seems very likely that the Sparry limestone of Dr. Emmons, is of the age of the Trenton. The question to be considered next, is this: Is there any sufficient proof that the Stockbridge limestone passes into and becomes this Trenton limestone?

We remark at once the absence of fossils from the Stockbridge limestone, throughout its extent in Massachusetts, where it is known to be of the same horizon. We also notice that in all the Taconic region, extending from the northern part of Addison county, Vt., through Massachusetts into Connecticut, (and further south,) there is almost a total lack of recorded fossil localities in the area of what may be considered the Stockbridge limestone. The fossils that have been found are mainly along the western border of the Taconic range, or are in the "magnesian slate" which constitutes the Taconic range.

We also notice that the line of limonite iron mines, as marked on the geological map of Vermont by Dr. Edward Hitchcock, and considered by him a belt of Tertiary age, runs along the eastern edge of the limestone area, and not far from the western edge of the quartzite area, thus coinciding with the possible strike of a limestone of the age of that which accompanies the Taconic ores in Minnesota and Wisconsin.

We note next the existence, in northern Vermont, of another limestone which has also furnished a large amount of marble, known as Winooski marble. According to Mr. Walcott, this limestone lies below the *Olenellus* fauna, and has not yet furnished any characteristic fossils.* He also says it is over 700 feet thick, (reaching 1,000 feet), and is overlain conformably by 8,000 or 9,000 feet of slates and schists; and in other places he estimates these schists at 14,000 feet, and refers them to the great Georgia formation. The query naturally arises—may not the Stockbridge marble be on the horizon of the Winooski marble? and may not the schists and slates that make up the Taconic mountains—its conformable companions—be the equivalent of the Georgia formation? In the Winooski region, at any rate, there is a marble formation directly overlain by 9,000 feet of primordial slates and schists belonging to the *Olenellus* fauna. We notice that in continuing southward, while these schists expand into a great area, and really come to make the Taconic range of mountains, the underlying limestone, according to Wing, Dana and Walcott, disappears entirely, and although there is a great non-fossiliferous marble belt, the limestone which constitutes it is, on the same authority, of Lower Silu-

*Am. Jour. Sci. (3), XXXVII. 384; XXIX, 330.

rian age, and overlies the same schists and slates—at least is of more recent date, although overlain by a second series of schists and slates. There is, therefore, no unreasonableness in suggesting that the Winooski marble may continue southward and deploy out on the flanks of the Green mountains, carrying with it its conformable companion, the Georgia slates and schists. We may go further, and affirm that, in the absence of proof to the contrary, the Winooski marble would be likely to extend southward. Its extension southward would be in a direction parallel with the folds of synclinal and anticlinal axes. If the supposed extension were across such pre-primordial axes, there would be reason to expect that some of them might cut it off. We have, therefore, in addition to the certainty of the presence of the Trenton limestone in southern Vermont, the probability also of the presence of the Winooski marble.

We next proceed to consider the question in the light of positive facts bearing on the probable existence of the Winooski limestone in central and southern Vermont, and in Massachusetts.

We find the earliest evidence comes from the researches of Mr. Wing, as presented by Prof. Dana.

We take up first those facts which tend to prove the existence of only one limestone, and afterward those that tend to show the presence of two.

1. *Facts that indicate the presence of but one limestone.* All these facts have been interpreted by Mr. Dana, and accepted by Mr. Walcott, as proving satisfactorily that there is but one limestone.

(a) *Fossils at West Rutland.* Great stress has been laid on this discovery by Mr. Wing. But if the description be examined in connection with its accompanying map,* it will be seen that the evidence is far from conclusive. The fossils are all in a comparatively narrow limestone belt which is isolated entirely from the principal marble belt. The beds all dip east toward the quartzite, and the appearance indicates that they pass below it. They cannot, however, pass below it, since the quartzite is in the bottom of the primordial, according to Walcott, and the fossils discovered by Mr. Wing are of the age of the Trenton. There is, therefore, proof of general irregularity at West Rutland, such that the dip and the relative position cannot be taken as indices to chronologic sequence. Therefore the eastern belt of limestone at West Rutland cannot be assumed to be the same stratum as that containing the fossils. Indeed, Mr. Wing particularly emphasizes the fact

*Am. Jour. Sci. (3), XIII. 334.

hat after search along the strike northward the West Rutland limestone ceases, and the upper and lower slate belts come together in the same manner as on the south. In this respect he corrects the official map of the Vermont geological survey.

(b) *Fossils at Sudbury.* According to Dana this limestone area is a narrow, isolated belt similar to that at West Rutland,* or has a narrow connection with it. The fossils indicate it is also Trenton, but there is no evidence that it is connected with the eastern marble belt.

(c) *Fossils at Hubbardton and West Castleton.* These are also far west of the great marble belt, and in the midst of the "great central belt of slates", in narrow belts of limestone, one being but sixty yards wide. There is here no connection with the great marble belt.

(d) *Fossils at East Cornwall.* The fossils identified here by Billings show the Trenton limestone. But this is also on the course of the great slate range, and seems to be affected by some irregularity similar to that at West Rutland, since the strata all dip eastward, and are represented to pass below the quartzite. The fossils in Shoreham, West Cornwall and Orwell, reported by Mr. Wing, while probably showing the Trenton limestone, are too remote from the marble belt to be considered, in this inquiry, as affording any demonstration one way or the other.

(e) According to Mr. Wing's observations this limestone containing Trenton fossils along the east side of the slate belt in the Otter Creek valley, continuing northward from West Rutland, passes in an unbroken area, in the northern part of Sudbury, round the northern end of the slate belt, and unites with a similar limestone on the western side, and thence passes southward through western Weybridge and Cornwall, having slates above it which he refers to the Hudson River slates. Whether this be correct or not (and we have no disposition to question it) the eastern belt of marble continues uninterruptedly in a belt further east, and wholly on the east side of Otter creek, and runs further north into Monkton, forming an independent northward prong, like that of a separate formation, accompanied all the way by the belt of iron ores, as represented on the geological map of the Vermont survey.† The synclinal therefore that is described here by Wing and Dana, may consist of the Trenton limestone, overlain by the Hudson River slates, but that will require a correction of the late map of Mr.

*Am. Jour. Sci. (3), XIII, 339.

†It probably runs below the Red sandrock, in Monkton, while the other limestone terminates in a flattened synclinal by the rising of the Red sandrock beneath it in the same town.

Walcott, for he has colored these slates as of the Georgia (Olenellus) formation.* At any rate, as long as Mr. Walcott differs from Mr. Wing in the interpretation of this supposed synclinal, Mr. Wing's reasoning and his observations cannot be taken as demonstrating the identity of the two limestones; which is the only point we wish to make at this place.

(f) *Fossils in New Haven.* So far as these are determined they depend on very imperfect specimens, and as they are in beds that underlie some quartzite, and which appear to be of the Winooski marble series (Dana), they do not have any bearing on the Trenton limestone.

(g) *Fossils discovered by Mr. Walcott.* So far as the new localities of Trenton fossils, lately brought to light by Mr. Walcott, have a bearing on this question, they are those which are nearest the eastern marble belt, viz., those on Mt. Anthony and those in Pownal.

Those fossils discovered in Pownal are taken to be from the Stockbridge limestone, or from the "eastern belt" of limestones, and as they concur in testimony with those from further north on the western side of the Taconic range, Mr. Walcott makes the unqualified affirmation (A. A. A. S., 1887, 213), that the Stockbridge limestone is of Trenton age. We cannot accept the inference, because we find reason to believe the Stockbridge limestone is not there represented. Anyone examining Mr. Walcott's map will see that there is at that point an abrupt jog to the eastward in all the formations. Coming from the north the belt of quartzite is suddenly broken off and does not appear except at several miles further to the south and east. The eastern belt of limestone, in the same manner, jogs several miles abruptly to the east, while the western belt ceases in the line of its regular trend and is thrown into the line of strike of the eastern belt. Whether there be at the same time a sinking of the Stockbridge limestone so as to allow the Trenton to make the surface rock, (as is quite probable regardless of the eastward jog), is immaterial. It cannot be denied that quite suddenly and singularly, all the formations are jogged out of their courses, a remarkable fact to which Prof. Dana has called attention. In general the Taconic range of hills runs through here, and some of these hills seem to be formed of synclinals of the Hudson-Trenton terrane, as represented, but the existence of the Stockbridge limestone in these hills is far from proven.

*See his map, Vol. xxxv, 346. *Am. Jour. Sci.*

Those fossils that are reported by Mr. Walcott from Mt. Anthony, and especially those from Graylock, are subject to the same explanation. Those found on the east side of Mt. Anthony leave room still for the strike of the Stockbridge limestone along east of Mt. Anthony, according to the coloring of Mr. Walcott's map, and Dr. Hitchcock's map represents it as continuous through Bennington and Pownal, accompanied by the iron ore belt.

(h) *Fossils discovered further south.* Some of the limestones further south are proven by fossils to belong to the primordial and some to the Trenton-Hudson terrane. But only on very general considerations could either of these be claimed to be the representative of the Stockbridge limestone. So far as this evidence goes it demonstrates the existence in Dutchess county of a limestone on about the same geological horizon as the Winooski limestone, and also on the same horizon as the West Rutland limestone, and it leaves us to infer that both the limestones continue in the line of strike between these points.

2. *Facts that indicate the presence of two limestones.* If we seek for the positive facts that go to show that there is another limestone, much lower than the Trenton, running through western Vermont and southward, we get the first evidence, (independently of Hitchcock and Emmons) again from Mr. Wing, and secondly from the stratigraphic descriptions of Prof. Dana.

(a) *Facts from Mr. Wing.* It should be borne in mind that by the discovery of fossils in the quartzite Mr. Walcott has demonstrated that it belongs in what he called middle Cambrian [Olenellus zone] but which he has later ascertained to be the lowest of the sub-faunas of the "Cambrian;"* Therefore there must intervene between it and the Trenton, not only the Winooski limestone, but the great Georgia formation, an interval that measures, in Vermont, at least 15,000 feet of sediments.

We find that Mr. Wing describes the quartzite as *interstratified with the overlying limestone*. This he does not once, nor twice, but commonly, and wherever he speaks of the contact of the two terranes.†

This is clearly brought out by his diagrams, and particularly by that giving a section from East Shoreham on the west to Leicester on the east. Whatever may be the errors of stratigraphy further west, which might be demonstrated respecting this diagram, there can be no question about so simple a point as the interstratification of a limestone with a sandstone, which is represented as oc-

*Position of the Olenellus fauna in North America. Am. Jour. Sci. xxxvii. 374.

†Am. Jour. Sci. xli. 340. 407. 414.

curing near lake Dunmore, in Leicester. It was near this place (lake Dunmore) that Mr. Walcott found primordial fossils in this quartzite. There could be no stronger evidence, not only that these two are of one age (and not one primordial and the other Trenton) but that they both belong in the primordial zone.

(b) *Facts from Prof. Dana.* Some of the localities described by Mr. Wing were visited by Prof. Dana,* who has given his own diagrammatic sections of the relations of the limestone to the quartzite, and has shown the same interstratification. Some such sections were made in New Haven and in Monkton; and his conclusion is to the effect that the Eolian limestone* includes "even limestones and dolomytes of the Red Sandrock series"—i. e., may contain limestones that belong to the *Olenellus* zone.

(c) We might mention here the fact that an "*Olenellus* limestone" has recently been described by Prof. Dwight in Dutchess county, N. Y., overlying an "*Olenellus* quartzite" (*Am. Jour. Sci.* XXXIV, 30); and that it occupies the area which Prof. Dana had colored on his map as Trenton-Chazy-Calciferosus. This only inferentially bears on the question of the extension of a primordial limestone from central Vermont to Dutchess county.

With this we think we have shown the interesting fact that there is a primordial limestone in western Vermont, the probable equivalent of the Stockbridge limestone, and that to it belong the numerous limonite iron deposits of the Taconic region. There is therefore, no good reason for rejecting the idea which we first entertained, viz.: that the iron deposits of the Taconic rocks in Minnesota (the Mesabi ores, excepting the titanic gabbros) are on the same stratigraphic horizon as the Taconic ores of western New England.

There are some corollaries that spring from this result to which we might call attention, but we will mention only one.—It retains the Stockbridge limestone in the primordial zone as a distinct terrane immediately overlying the quartzite, or granular quartz, in the exact place assigned it by Dr. Emmons in his Taconic system.

NOTE.—At the late meeting of the Geological Society of America, Washington, D. C., Dec. 29, 1890, Mr. J. E. Wolff, of the U. S. Geological Survey, reported the discovery of characteristic primordial fossils in the "eastern belt" of limestone at Rutland, Vt., confirming the conclusions of this paper.

**Am. Jour. Sci.* XIII, 407-409, 411.

*This was the name applied by Hitchcock to the whole Vermont marble belt, on the ground that it was essentially one formation.

APPENDIX C.

THE EASTERN EQUIVALENTS OF THE MINNESOTA IRON ORES.

N. H. WINCHELL.

[Read Oct. 7, 1890, before the Minnesota Academy of Natural Sciences.]

There has been for thirty years or more a radical division of sentiment among American geologists as to the value of lithological evidence in making chronologic comparisons between the Archæan stratigraphy of different places. One school is disposed to consider a resemblance of lithology that may exist between two places, however remote from each other, as evidence of identity or near identity of age for the rocks that show such resemblance. This view has been urged by Dr. T. Sterry Hunt, and has been the key by which he has attempted to make out the order of succession of the crystalline rocks not only for the United States and Canada, but for Europe and other parts of the world. The other school, which is represented by Prof. J. D. Dana, discards entirely the guide of common lithology in deciphering the stratigraphic succession of the rocks of the earth's crust, and particularly the strata of the crystalline rocks, and maintains that the only guide that we must follow is that of paleontology, and in the case of the Archean or Azoic, where manifestly this guide is wholly wanting, they assert that it is impracticable to determine with certainty any order of succession.

It is not my purpose, at this time, to compare and discuss the relative merits of these opposing views. I have to admit, however, that in attempting to show what are the eastern representatives of the iron ores of Minnesota, I have to rely largely on lithologic evidence. Until recently there was but little known of the stratigraphic relations of the iron ores of the Northwest to their associated rocks, and still less of any relations they might sustain to ore deposits in Canada, New York or New England. To be sure we knew, not from lithology only, but from paleontology, that our ores were not the stratigraphic equivalents of the black-band and kidney ores of Pennsylvania, which belong in the Carboniferous, nor of the dye-stone ores of Georgia and Tennessee, which

are in the upper Silurian, nor of the limonites of the lower Mississippi valley, which are in the Cretaceous. These were determined by the discovery of characteristic fossils in those formations. When, however, we descend the geological scale we find the guidance of paleontology growing weaker and weaker. It barely helps us to lay hold of the very uppermost of our ores and by its light to fix their age. All the rest, whether in Minnesota or in the eastern part of the United States, is left to be determined by lithology, though lithology is aided by chemistry and metallurgy, and latterly by stratigraphic researches in the field.

But while all is blank, so far as the light of paleontology is concerned, below the primordial zone, we find some assistance, as already stated, in looking at the older iron ores of the country from different points of view. We may consider then, *first*, from a chemical or metallurgical standpoint; *second* from the standpoint of their associated mineralogy, and *thirdly*, from the standpoint of their comparative stratigraphy, so far as that has been determined.

It would be manifestly impossible, at this time, to enter into the details of the comparisons that might be made between the Minnesota ores and those of the eastern portion of the United States. It will be only proper here to state some results rather dogmatically, perhaps, for a scientist, and to refer those who desire to examine the evidence to the authorities themselves, and to a forthcoming report on the iron ores of the state in which the facts are given more in detail.

If we should arrange a table of the Minnesota iron ores, calculated so as to show at a glance their general characters in all these respects, we should have to place the youngest at the top of the column, and the oldest at the bottom, and we could express the other characters in added columns, and the table would be some-like this:

AGE.	STRATIGRAPHY.	CHEMICAL AND METALLURGICAL QUALITIES.	ASSOCIATED MINERALOGY.
Taconic (primordial) Animlike.	Carbonaceous slates. Quartzites, Traps. Ferruginous Red Shale.	Not worked, nor known to be important.	Carbonaceous Slates, cherty; impure quartz, fragmental and chalcedonic.
Taconic (primordial). Mesabi.	GABBRO and Augite-syenite and Red Felsyte.	TITANIC MAGNETITE.	Labradorite, etc., Augite, Menaccanite, Olivine, Biotite.
Taconic (primordial).	DOLOMYTE. Cherty, Jaspilitic impure. Quartzites; Slates. Flints.	HEMATITE, carbonate, limonite. Often maugan- esic in Wisconsin. Soft.	Dolomite (marble). Chalcedonic silica.
Taconic (primordial) Pewabic.	QUARTZYTE. Gabbro. Lherzolyte.	OLIVINITE MAGNETITE, often quartzose and sulphur-bearing.	Fragmental quartz. Olivine, Hornblende or enstatite. Actinolite. Chalcedonic silica.
Keewatin (Archean).	GREENSTONE, Chlorite and sericite schists. Graywacke.	Bessemer HEMATITES. Scant magnetite. No sulphur. Very low in phosphorus.	Plagioclase. Uralitic Hornblende. Chlorite. Sericite. Muscovite. Jaspilite. Fragmental Quartz.
Vermilion (Archean).	CRYSTALLINE SCHISTS.	Bessemer MAGNETITES, (rarely titanite).	Biotite. Muscovite. Hornblende Quartz. Orthoclase. Plagioclase.
Laurentian (Archean).	GREISS and crystalline schist.	Not known in Minnesota.	

The table shows five important ore horizons, three of which fall within the Taconic or primordial zone. In the columns the important characteristics are expressed by words in bold-faced type, and generally stand first in the series. Those ore horizons which lie below the primordial zone, and which in Minnesota are the most important, so far as they have been exploited, are more in doubt, as to their eastern equivalents, than those that are embraced in the primordial; and here we have to rely on the published descriptions of eastern geologists for all the data that we have that will enable us to make a comparison. In the table the formations are expressed that belong immediately above and below all of the ore horizons, in order to convey a correct general idea of the place of the ores in the general stratigraphy.

Beginning with the lowest of these ore horizons, that of the crystalline schists, before looking for its possible stratigraphic equivalent it will be necessary to remark that the crystalline schists are derived from a metamorphosis of sediments which probably were of the nature, before metamorphism, very nearly of the Keewatin schists that overlie the crystalline schists and into which they graduate stratigraphically and mineralogically by insensible transitions. The intensity of the metamorphism varied from place to place. In some places it involved greater thicknesses of the original sediments than it did in others. In some places it invaded apparently all the sediments that preceded the primordial age, so that there is nothing to be found of any such formation as the Keewatin. It was all converted into crystalline schists. In other places those old sediments were at first more abundantly supplied with fragmental or other quartz, and when thus metamorphosed, instead of forming a crystalline schist in which are large amounts of biotite or hornblende, the metamorphic products from the original basic elements of the sediments, the resultant rock is a siliceous gneiss, or simply gneiss. When the metamorphism was carried to fusion or plasticity, those old sediments were locally displaced and made to assume the aspects of eruptive rock. In that way large areas were invaded by molten rock of an acid nature, and in innumerable instances it was thrust irregularly amongst the broken or bent unfused sedimentaries. Hence, when we seek for the stratigraphic equivalents of the ores of the crystalline schists we may find them in rocks which elsewhere have been denominated gneiss, and which has been included in the Laurentian. I do not wish to intimate that there could have been possibly a conversion of a crystalline schist at any certain point into a gneiss, by a supposed increase of metamorphic action, involving a conversion

of the rock from a basic percentage of silica, or from any percentage of silica, to one having less silica, for I consider the crystalline condition of the crystalline schists as complete as that of the gneiss. Their only difference consists in the relatively greater amount of silica in the gneiss than in the schist. This difference is not an effect of metamorphism, but is caused by an initial greater percentage of silica in the sediments that were transformed to make gneiss than in those that were transformed into crystalline schists. The term gneiss is variously applied by geologists, and it is a convenient term for that reason, so long as we retain a distinct idea of its scope and application. We shall find, further, that what has been denominated gneiss by one geologist, and mapped as gneiss, will be by another included under crystalline schist, and *vice versa*.

It so happens that nearly all the magnetic ores of Canada (excepting only the titaniferous) have been described as occurring in gneiss, and have nearly always been placed in the Laurentian. We find they answer in all other respects to the magnetites that belong to the crystalline schists in Minnesota. In northeastern New York, according to Mr. C. E. Hall,* there are extensive magnetite deposits in the Laurentian gneiss, or "Lower Laurentian" which are non-titaniferous. They occur in the hornblendic gneisses and micaceous garnetiferous gneisses, precisely as they do in Canada, and there can scarcely be a doubt of their equivalence with the magnetites of the Vermilion series of the Northwest. They are in the eastern and southern portions of Essex county, Port Henry being in the center of the mining industry which is based on them. These deposits are large, and have been extensively worked for many years. This fact, however, should not mislead us in estimating the probable value of the magnetites of the crystalline schists in Minnesota. The crystalline schists and the gneisses are more largely developed on the eastern borders of the United States, at the expense, as already explained, of the softer schists and graywackes of the Keewatin, and it is probable that the contemporary equivalent of the ores of the gneisses or the crystalline schists of eastern New York, if they had any western representative, may be found in the Keewatin of the Northwest, where the crystallization of the lowest schists seems not to have been so profound nor extensive.

I do not know of any ore deposits in New England that can be parallelized with those here under consideration. In New Jersey and in eastern Pennsylvania, however, the same class of iron ores

*Report of the State Geologist for 1883.

occur. They continue southward into western Virginia and northern Georgia, giving rise in North Carolina to the most valuable iron ores.

If we next consider the Bessemer hematites of Minnesota, we do not find their exact eastern equivalents clearly defined and free from ambiguity at any place. The nearest approach to parallelism is in the Marquette region of Michigan, (typically the Jackson mine at Negaunee), and perhaps some of the mines in the Menominee district. But it appears that at Negaunee the geology is complicated by having both iron formations present within narrow geographic limits—that is the Keewatin and the Taconic—and there has not been any thorough re-examination of the region published since this fact was discovered. But that the Greenstone ores of the Keewatin are abundantly represented in Michigan cannot be questioned. We are not aware that at any place further east have these Bessemer hematites been identified. There is but a scanty representation of the schists that enclose these ores throughout the east, and a still more scanty knowledge of any such ores. This can easily be explained on the hypothesis, already stated, that the softer schists of the Keewatin have been converted, by greater metamorphism, into the crystalline schists or gneiss which prevail so largely further east, and that probably the eastern chronologic analogues of our Keewatin hematites are to be found in these schists in the form of non-titaniferous magnetites.

When we reach, however, the primordial ores there is a more constant and interesting parallelism. We can here avail ourselves not only of the testimony of paleontology and common lithology, but of common stratigraphic succession, common chemical and metallurgical qualities, and similarity of mineral associations. These lines of testimony convergently point with certainty to the eastern parallels of our primordial ores. It is through the long continued researches and descriptions of Prof. J. D. Dana, seconded by those Mr. Walcott, Prof. Dwight and Dr. J. P. Kimball, that we have learned something of the stratigraphy and the mineralogical environments of the eastern ores of this horizon. But it is to the report of C. E. Hall, on the ores of northeastern New York, already referred to, that we have to look for the clearest and most consistent systematic exposition of these ores.

When the descriptions of Hall are compared with those of northeastern Minnesota as published by the Minnesota survey, each wrought out independently, and even without the knowledge of the other, they are found to agree in all the directions in which we may look for evidence on this comparison. The great north-

south valley of the lake Champlain and the Hudson river separates the region of the New York ores from that of the ores of western New England. This depression dates from Archean time, and we may reasonably anticipate finding the geology which expresses the history of the valley, very nearly identical on its eastern and western slopes. Dr. E. Emmons first properly interpreted the geology of this valley, and if his views had been freely accepted by geologists of his time, and if, from his position as a starting-point, the labors of subsequent geologists had proceeded to add to and build up a consistent scheme of stratigraphy and nomenclature, it is not too much to say that in such research American science might have led the world by many years. It is only lately that the interpretation that Emmons placed on the stratigraphy of the rocks of the Champlain-Hudson valley, has been verified. As long, for instance, as the Green mountains were considered to date from the close of the Lower Silurian, as maintained by Dana and Logan, as long as the Taconic mountains were claimed to be composed of modified sediments of the Upper Silurian, or even of the Lower Silurian, which appears yet in the papers of Dana and Walcott, as long as it continued to be maintained that there is no reliance to be placed on identity of lithology on opposite sides of the same valley, and that by a mysterious process of local metamorphism, or "temporary non-deposition," these old rocks may change from a fragmental quartzite, within thirty miles, to a chloritic or magnesian schist, on the other side of the mountains—so long, I say, as such stumbling-blocks were allowed to impede the correct interpretation of the valley, it was impossible to institute any reliable parallelism between the western and the eastern ores. These stumbling-blocks are gradually being rolled away, and it is to be hoped that by the opening of the twentieth century they will all have disappeared. Much patient labor is yet to be undergone. It is hard to eradicate error that has become established. It has to be rooted out by laborers from many directions. Its entrenched position has to be slowly overthrown by a process of sapping and mining. Then in its place may be erected a fortress that will forever be invulnerable. Error, however, never capitulates. It has to be crushed to death. Its most vicious sorties are made just before it expires.

There is a system of strata in the Champlain-Hudson valley which is the exact parallel of that of the Taconic (primordial) in the Northwest. Beginning below, the Potsdam sandstone,* which

*The writer wishes to correct the view published by him in the *American Geologist* a few years ago ("A Great Primordial Quartzite," vol. 1, p. 178.), that the granular quartz

we consider here the equivalent of the granular quartz, lies, on both sides of the valley, first over the Archean gneiss and schists. It runs under the valley. It appears near lake Champlain, and it rises on the westward slopes of the Green mountains. Over this quartzite, which has been proven by fossils to be of primordial age, is a great dolomite, which at several points furnishes a fine marble—the Winooski and Stockbridge marble. This marble is so intimately interstratified with the quartzite (according to Rev. Mr. Wing and Prof. J. D. Dana) that its lower part is not separable from it. They are both, therefore, primordial. Above this marble is a large body of slates and schists which constitute the Georgia formation of Vermont. These are all represented to be in conformably successive stratification. They are all primordial.

Now, according to Dana and Kimball, the iron ores of western New England, so far as they are wrought, are closely connected, in some way which has not yet been fully made out, with the Stockbridge marble, or with some of the schists that overlie it, and they are represented to occupy a pretty persistent course, in a direction southerly, toward Hudson, N. Y., and then, crossing the Hudson river, the belt of country occupied by them continues toward northern New Jersey and into Pennsylvania.

There is, however, in Essex county, N. Y., an element in the general geology which brings out clearly the parallelism of the primordial Minnesota ores with those of which we are speaking, viz., the Potsdam quartzite and the Stockbridge marble are broken up and overwhelmed in a great outbreak of what Dr. Emmons styled "hypersthene rock," which is here considered the parallel of the gabbro of Minnesota, which in a similar manner disrupted and overwhelmed the quartzite (Pewabic) and the cherty dolomite which embrace these ores in the Northwest. On the east side of the Hudson valley this event took place in Cortland, N. Y., and there in the same manner, as described by Dana, it is inextricably mingled with similar rocks, which he carefully traced southward from Stockbridge in Massachusetts.

Our lowest primordial ores are in the Pewabic quartzite. They are magnetic. Their eastern equivalent appears in the "quartzose magnetites" of Essex county. They belong below the gabbro of the "Upper Laurentian." Our next higher ores, while not well

probably overlies the black slate of the Taconic system, and is the equivalent of the red sandrock of Vermont. The red sandrock appears to be a part and near the top of the "Georgia series," and above the Winooski marble, but the "granular quartz" lies below the Winooski marble. The typical Potsdam is probably the "granular quartz." But the red sandrock, and also some light-colored loose sandstones still higher have very largely been regarded its equivalent.

developed in Minnesota, yet are known, and in Wisconsin, according to Irving and Van Hise, they constitute the chief deposits of the Penokee-Gogebic range. Their eastern equivalents are the limonitic hematites that are so common in Vermont, in eastern New York and along the Appalachian range in Pennsylvania. The next higher group embraces the titanitic magnetites, both in Minnesota and in eastern New York. These do not occur in New England, so far as known, but there is no doubt that the magnetite in the gabbros of Cortland, N. Y., is titanitic, and there is no reason why it may not be expected to exist there in large quantities.

There is more or less ore in a still higher horizon, which I have not enumerated in the list of our ore-bearing horizons, viz: in the slates above the gabbro. Some of the Wisconsin mines appear to be in this horizon. Some of the Hudson valley mines also belong, apparently, in this interval, according to late descriptions by Dr. J. P. Kimball.

If we consider the evidence of parallelism of these ores from a chemical and mineralogical point of view, we find them grouped thus:

<i>Minnesota.</i>	<i>Eastern New York.</i>
Titanic magnetites.	Titanic magnetites.
Limonitic hematites, manganesic	Manganesic limonites
Olivinitic magnetites (sometimes with sulphur.)	Sulphur-bearing magnetites.

Their associated mineralogy has been sufficiently indicated in presenting their general geology. All their metallurgical qualities, it is scarcely necessary to state, bear out the same close analogy.

Conclusion. We may sum up the results of the discussion in a few brief sentences:

1. Of the five well-marked iron-ore horizons of Minnesota, four are well known in the eastern part of the United States, and can be identified by their identical stratigraphy, their chemical characters, and their associated mineralogy.

2. That which is not yet identified in the eastern part of the United States, yet possibly exists there under the guise of magnetite instead of hematite, the difference of condition being due to more powerful action of hydrothermal metamorphism on the strata concerned, along the borders of the continent than in the interior.

There is a very obvious corollary to these results which should find expression here, viz: There is a similarity of lithology between these terranes in Minnesota and eastern New York, extending from the crystalline schists upward through the Taconic, such that under its guidance alone these ores could be referred to their stratigraphic position.

APPENDIX D.

LIST OF ROCK SPECIMENS MENTIONED IN THIS BULLETIN.

1 (H). From the point in S. E. $\frac{1}{4}$ Sec. 20, 62-15. Vermilion lake. A compact, semi-metamorphosed rock, containing rounded grains of quartz. pp. 25, 68.

2 B (H). From Ely island, S. E. $\frac{1}{4}$ Sec. 17, 62-15. Pebbles of quartzite, jasper, etc., from the felsitic conglomerate, No. 2 (H). pp. 45, 46.

126. Iron sand; beach of lake Superior, near Beaver Bay. p. 141.

270. Graphitic rock. Pigeon Point, S. W. $\frac{1}{4}$ Sec. 32, 64-6 E, nearly on the axis of the point. Rock is metamorphic and charged with graphite nodules. p. 123.

312. Quartzite conglomerate from north shore of Gunflint lake. Composed of a matrix of siderite and silica containing flint and quartz fragments. pp. 121, 129.

355 (H). Gray rock, feldspathic and siliceous, containing magnetite. Sec. 29, 59-14. p. 119.

356. Greenstone. Kawasachong falls, township 63-11. pp. 37, 38.

362 (H). Stratified magnetite and quartzite or siliceous schist. N. W. $\frac{1}{4}$, N. E. $\frac{1}{4}$ Sec. 19, 60-12. p. 133.

417 (H). Micaceous hornblendic schist. S. E. $\frac{1}{4}$, S. E. $\frac{1}{4}$ Sec. 25, 63-10. pp. 7, 8.

418 (H). Biotitic hornblendic schist. N. W. forty, Sec. 4, 63-12. p. 7, 8.

437. Sideritic quartzose rock of Taconic age. Sec. 31, 59-14. pp. 119, 123, 129.

452 (H). Diamond drill cores of quartzite and magnetite. West of Gunflint lake, Sec. 28, 65-4. p. 131.

453 (H). Drillings from one-eighth mile south of the "camp" in Sec. 28, 65-4. p. 131.

511 A (H). Contact specimens of diabase and jaspilyte. N. E. $\frac{1}{4}$ Sec. 8, 63-9. pp. 77, 78.

538 B (H). Diabase taken ten feet from contact with mass of jaspilyte. S. W. $\frac{1}{4}$, N. W. $\frac{1}{4}$ Sec. 4, 63-9. p. 38.

543 (H). Magnetic iron ore from the crystalline schist on north line of township 63-12. p. 11.

552. Plumbaginous quartzite. Pigeon Point, near the trail to Parkerville, Sec. 32, 64-7 E. p. 123.

598. Compact, light-red, dolomitic, sandrock. Silver Islet, lake Superior. p. 123.

696. Nodules of coarser gabbro, from gabbro, Sec. 36, 65-3. p. 135.

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THE GEOLOGICAL MAP.

The geological map which will be found in the cover pocket, is as nearly correct as we can make it at present. There has been no thorough examination over the western portions of the included area, between the line of the Duluth and Iron Range railroad and the Diamond mine near Grand Rapids on the Mississippi river. The outlines of the formations in this region, as represented, are laid down by information that has been obtained of explorers and from some meager descriptions by a few geologists who have been through on the Mesabi range. It is evidently a region where an important series of iron mines will finally be established, as it covers the northern outcrops of the rocks of the Penokee-Gogebic range as found on the south side of lake Superior. The limitations of too little time and less money have prevented us from completing the survey in this region. In like manner the western extension of the Vermilion range of iron-bearing rocks is almost wholly conjectural, having but few and scattered data for basis. It was thought better to indicate as nearly as possible the course of these formations than to leave the space entirely incognito.



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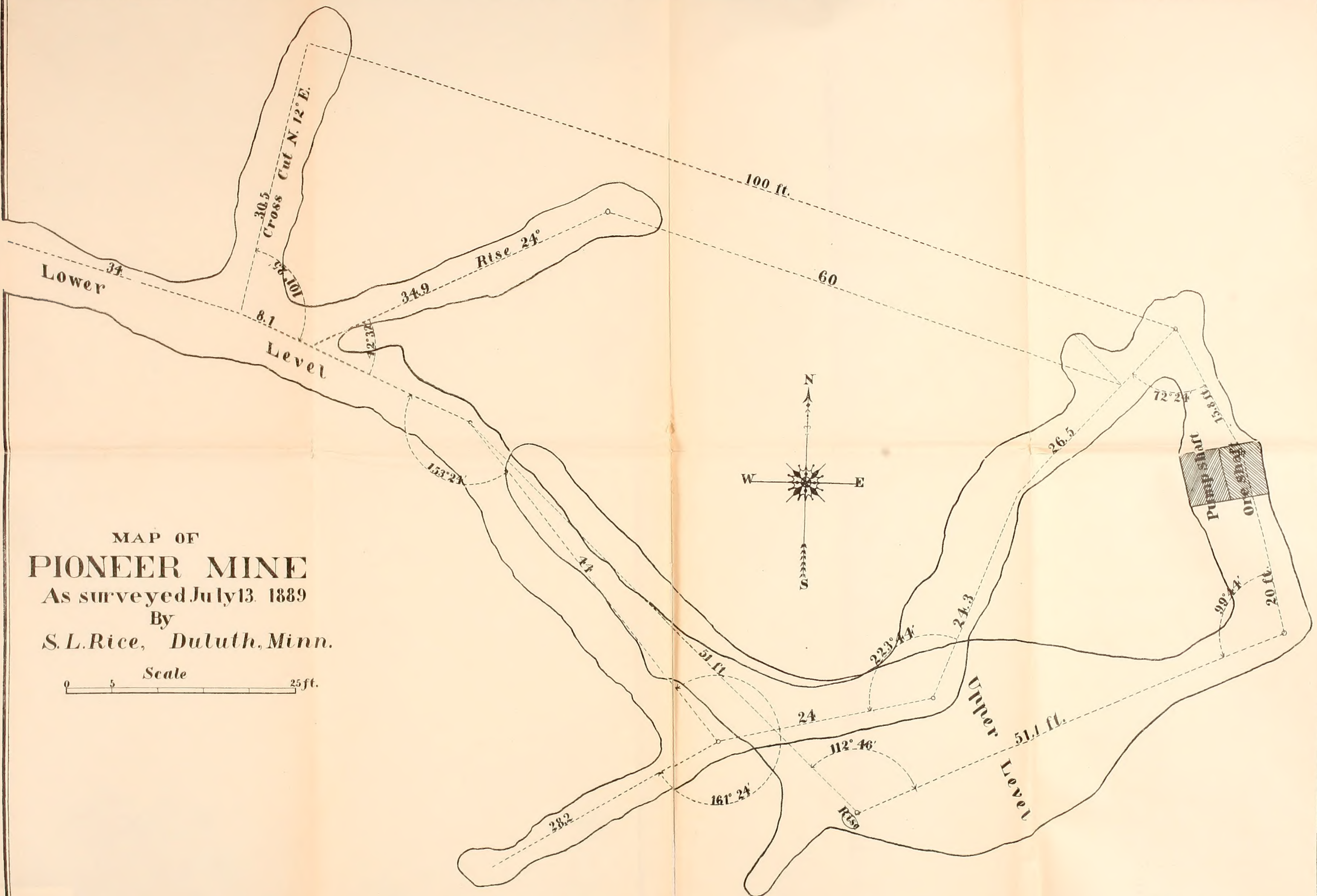
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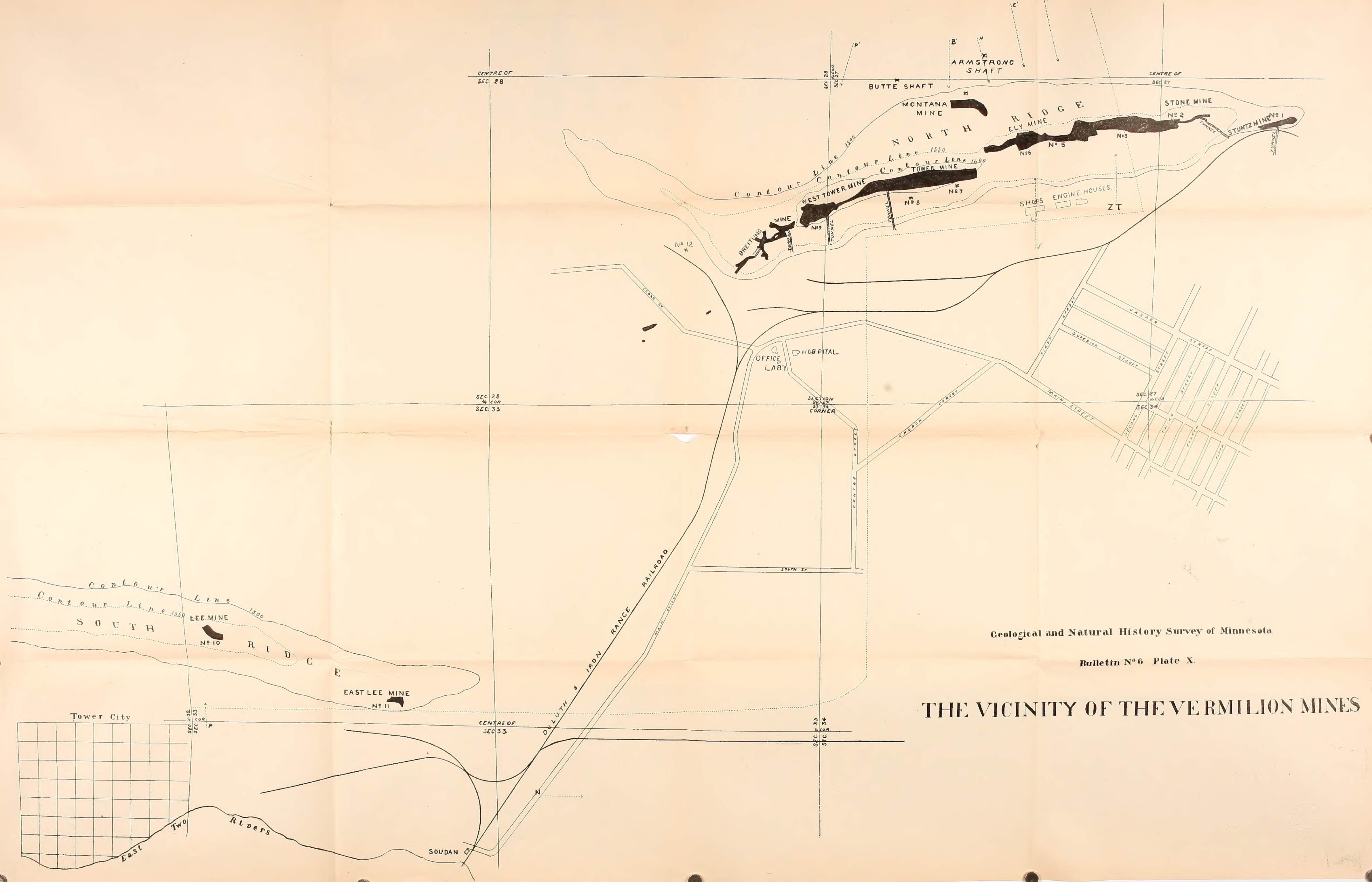
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The iron ores of
Minnesota
Winchell, N. H.

MAP OF
PIONEER MINE
As surveyed July 13. 1889
By
S. L. Rice, Duluth, Minn.

Scale
0 5 25 ft.





Geological and Natural History Survey of Minnesota

Bulletin No. 6 Plate X.

THE VICINITY OF THE VERMILION MINES

